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Cognitive Mapping–Driven Strategic Decision Support Framework for Chief Technology Officers

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In high-tech environments, decision-making is faced with complexity, uncertainty, and dynamic changes. Hence, Chief Technology Officers (CTOs) would require some powerful tools to make strategic technology-related decisions. One such powerful tool is Cognitive Mapping, which aids CTOs in visualizing complex decision problems, identifying key variables, and structuring strategic options. This paper aims to propose a Cognitive Mapping-based conceptual decision support framework. Qualitative research methodology is adopted for this study, since the data were collected using in-depth interviews, and analysis of transcribed interviews was done using ATLAS-ti software. By systematically identifying critical inputs, decision-processing components, and strategic outputs that characterize the CTO's decision ecosystem. The cognitive map developed from these insights is used to structure a three-stage SDSS framework, which offers a structured approach to navigating technological uncertainty and organizational complexity towards arriving at a decision. The paper proposed framework aims to bridge the current gap between strategic management theory and practical technology decision-making, offering a generalizable solution applicable across various high-technology industries.

Keywords: Chief technology officer, Cognitive mapping, Conceptual framework, Management of technology, Strategic decision support system

Introduction

A high-tech business environment is faced with complexity and uncertainty.[1] In order to thrive, organizations have specialized leaders such as Chief Technology Officers (CTOs), who are technologists and have both strategic and operational roles in an organization.[2] Emerging technologies, changing consumer preferences, and technological disruptions generally lead to frequent fluctuations in a business environment, which pose challenges to organizational success. Hence, CTOs need advanced and specialized skills, aided by a Decision Support System (DSS) to navigate such challenges. An effective DSS has peripheral vision to detect weak signals and indicate the upcoming opportunities as well as threats. Advances in computing capabilities and the widespread adoption of web technologies have expanded the scope of DSS to cater to increasingly complex technological challenges.[3]

Literature suggests that the CTO's role has been evolving towards more strategic and outside organization. In rapidly changing environments, DSS can play a pivotal role in helping CTOs formulate effective technology strategies, enhance decision-making quality, and manage risk and uncertainty. A well-designed DSS can significantly strengthen a CTO in proposing strategic technological decisions. Such DSS are known as Strategic Decision Support Systems (SDSS). This necessitates a comprehensive review of the literature on DSS. Despite its potential, there remains a notable gap in SDSS framework for CTOs and it could be a valuable contribution to both academic research and practical application.

To address this research gap, this paper presents the use of qualitative analysis to create cognitive map. Cognitive maps are visual representation of mental models.[4] Mental models of leading CTOs from various industries are recorded in the form interview transcriptions. ATLAS.ti software was used to generate themes and identify inter-relationship among them. The network feature of ATLAS.ti is used to visualize cognitive maps. The cognitive maps are further adopted into the framework of SDSS for CTOs.

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Literature Review

This section provides review of literature on strategic technological decisions, evolving role of CTO, and DSS.

A CTO is required to support strategic and operational decisions related to technology for success of an organization. In the dynamic business environments, CTOs are supposed to demonstrate special skills and powerful tools to support their decisions for the organizations. There are critical decisions with an emphasis on technologies for long-term planning to enhance market share of the organization.[5] CTOs are required to coordinate technological efforts among internal business units and corporate research to build synergy.[2] To develop technology strategy, organizations gather data from both internal and external sources and use the tools provided in DSS to get intelligence. This approach is useful to envisage the environmental fluctuations, due to emerging technologies, as incredible opportunities and threats often begin as weak signals from the periphery of market boundaries. DSS helps organization to sense, interpret, and act on the signals successfully to build a peripheral vision.[6] One of the key responsibility of CTOs is to translate technological competence into strategic business decisions related to changes in product and process.[7] Change in the role of CTO is highly influenced by different style of leadership, which depends primarily on the industry's technological intensity and its importance to business strategy.[8] A CTO is meant to be the senior most technology leader in an organization.[9] This emphasizes the significant role of a CTO in strategic decision making and future planning, important to the success of an organization.[10]

A Chief Technology Officer (CTO) plays a vital role in shaping both strategic and operational technology decisions that are critical to a firm's long-term success. In today's rapidly evolving environment (marked by accelerating technological change and shifting market dynamics), CTOs must possess specialized skills and be supported by robust systems to navigate uncertainty and complexity effectively. Strategic technological decisions are essential for activities such as long-term planning, enhancing competitive positioning, establishing effective technology management practices, and ensuring coordination across business units and corporate R&D to foster synergy and scalability.[2,5]

Top executives usually seek views and opinions from experts and colleagues, which they want to be based on facts and evidence. Sometimes, they decide based on those views and ideas, and else they go on with their gut feelings. Processing data generate opinions based on facts and evidence to get intelligence. Decision support models help in processing the raw data and information into the desired intelligence report. A DSS is required to help in decision making in organizations. It's interactive in nature, has flexible model, and developed to adapt according to various information sources with objective to support decisions in uncertain business environments. Having a friendly User-Interface and User-Experience (UI/UX), it allows CTO to gain insights using various quantitative models e.g. linear and nonlinear programming, simulation techniques, mathematical models and Artificial Intelligence-Machine Learning algorithms) and qualitative methods (e.g. Delphi, interviews, focus group). It also helps reduce time required to make decisions. Traditionally, DSS consists of five subsystems, each for data, model, knowledge, user-interface and user/ decision-maker.[3] It can provide descriptive, predictive and prescriptive types of analytical support. The required information metrics of DSS can be data centered, which needs quantitative measures (such as who, where, when, what) or human-centered, which needs qualitative measures (why, how, so what). DSS can be categorized based on the nature of the problem they address (ranging from structured to semi-structured and unstructured) and their application level, such as operational control, managerial oversight, or strategic planning.[11] Strategic decisions involving unstructured problems typically include activities like mergers and acquisitions, research & development planning, and launching new products. This study concentrates on developing a DSS framework aimed at supporting strategic planning in contexts where decisions are semi-structured or unstructured.

A DSS is an interaction based computerized system that supports decision-makers exploit data and models to answer unstructured problems. It is focused on a strong emphasis on the following features: designed for senior executives and top-level managers, decision-focused systems prioritize adaptability, responsiveness, and user-driven control, while accommodating the unique decision-making preferences and styles of individual leaders. DSS are generally classified into two primary categories: data-driven and model-driven. The latter employs computational tools that allow decision-makers to apply both quantitative and qualitative models to analyze semi-structured or unstructured problems. A typical model-driven DSS comprises three core components: a data management module that draws from databases or data warehouses; a model management module, which contains analytical models relevant to the decision at hand; and a dialog interface enabling users to interact with the system by entering inputs, selecting models, and conducting scenario-based or sensitivity analyses. This user interface facilitates deeper understanding through "what-if" explorations. Over time, traditional DSS platforms based on operations research have matured to include knowledge-based models, which use inference mechanisms such as rules or Bayesian Belief Networks (BBNs) to support or enhance decision-making, particularly useful under uncertainty.[12]

The speed of strategic decision-making significantly influences organizational performance.[13] The increasing interest in applying expert systems to business contexts reflects the evaluation of Information Systems (IS), which have progressed from batch processing to interactive systems, and now to more intelligent, AI-enhanced tools. While conventional DSSs are widely implemented, they often lack the cognitive path needed to fully replicate the reasoning process of human decision-makers. In contrast, expert systems (originating from successes in domains like medicine and engineering) integrate Artificial Intelligence (AI) to offer more nuanced, context-aware decision support. Such systems incorporate both qualitative insights and quantitative data, drawing on expert knowledge accumulated through years of experience. However, developing these systems presents unique challenges, including the absence of standardized methodologies, dependence of the expertise of system designers, and the unstructured nature of decision processes in business environments. When expert systems are commercialized for a broad user base, design complexity increases. These systems must accommodate users with varying decision styles, knowledge levels, and cognitive preferences. Key design challenges include: misalignment between the user's mental model and system logic; divergence in problem solving strategies; the impact of individual user characteristics on system interactions; difficulty in defining the boundaries of the problem and knowledge domain for diverse users; the integration of insights from multiple experts. Many of these interact with findings in cognitive science, AI and IS research. For instance, user interface design, user involvement, and system development principles from IS studies (alongside cognitive psychology insights into problem representation, learning, and expert-novice distinctions) offer valuable guidance for building robust, user-aligned expert systems.[14]

A Decision Support System[15] serves as valuable tools for addressing complex and diverse management and business challenges.[16] A SDSS stands apart from conventional systems by its capacity to manage unstructured problems through integration with the decision-maker's cognitive processes.[17] It supports advanced functionalities such as business modeling, scenario analysis, and sensitivity testing. These systems often embed conceptual models and offer interpretative tools (such as case examples, explanatory content, and usage guidelines) to assist decision-makers in navigating strategic thinking. They have proven particularly effective in helping organizations formulate and validate strategies for markets and products.[18] SDSSs have been successfully applied across various decision-making contexts, particularly where problems are ill-structured (situations too complex or novel to be fully modeled analytically). These environments call for the combination of human expertise and computer-aided analysis.[19] Research indicates that decision-making quality improves when the design of a DSS align well with the task and reduces cognitive load for the decision-maker.[20] Cognitive loads can be reduced by incorporating mental models such as cognitive mapping in DSS. Recent advances in computing technologies, including cognitive computing, have significantly enhanced the responsiveness, precision, and scalability of DSS platforms.

There are many applications of cognitive mapping and the use of mental models to explore decision making. Strategic cognition refers to the belief systems and interpretive frameworks used by senior management to understand the organization's environment, strategy, and portfolio. These mental models guide both sense making (the process of interpreting complex signals) and sense-giving, where managers use symbols, language, and strategic narratives to align the organization's understanding and action. At the individual level, top executives' cognitive structures and reasoning patterns have a significant influence on strategic decision outcomes, particularly when contextualized within the firm's specific challenges. While many studies on strategic cognition focus on collective processes, individual cognitive perspectives (especially those of CTOs) offer deep insights into how technological strategies are formed and implemented.[21]

While the extant literature highlights the importance of strategic decision-making by CTOs, especially in unstructured or semi-structured problem contexts, there is noticeable absence of decision support system specifically tailored to the CTO's strategic needs. To address this gap in the literature, this research is conducted to propose a strategic decision support system framework that reflects the cognitive processes and strategic responsibilities of CTOs. In the next section, the research methodology for the research objective of this research is explained. This research emphasizes the use of behavioral decision theory and cognitive mapping to model how CTOs approach strategy formulation.[23] Cognitive maps serve as tools to extract and represent expert knowledge in complex domains, offering a structured way to articulate and analyze interdependencies within a strategic decision environment.[24]

Research Methodology

This study follows a qualitative exploratory research design, suitable for investigating complex, context dependent phenomena such as strategic decision-making by CTOs, where in-depth understanding of context and stakeholder perspectives is essential.[25,26] The objective is to develop a conceptual framework for a Strategic DSS, grounded in real-world insights and cognitive patterns of technology leaders across organizations.

A purposive sampling approach was used to select participants having CTO position as the selection of participants is based on specific characteristics such as management of technology domain in high-tech industries, more than 10 years of work experience in the domain, experience of strategic technological decisions. The sample reflects various across industry types, organization sizes, and stages of digital maturity, thereby enhancing the transferability of findings.[27]

Thematic analysis was employed, beginning with open coding to extract key concepts from interview transcripts, followed by grouping into axial codes or themes.[28] It's a powerful tool to capture mental models of CTOs. To bridge cognitive and strategic decision-making, the study used cognitive mapping, a method that graphically represents how decision-makers perceive relationships among variables, constraints, and outcomes.[4,29]

To ensure the rigor in this study, member checks were conducted with selected participants to confirm the interpretations of their inputs. Peer briefing and external review helped mitigate researcher bias and refine the framework. All analytical procedures were documented in detail to maintain transparency and reliability.[22] Ethical approval was secured from the corresponding academic institution. Informed consent was obtained from all the participants, with clear communication regarding the purpose of the study and their right to withdraw at any stage. Identifiable details were removed to ensure confidentiality of the participants.

To better understand a CTO's decision-making process, we captured the mental model of a CTO's decision-making process in organizations. A cognitive map is created by analyzing interviews of CTOs and further used to derive a conceptual model for strategic DSS. The purpose of a conceptual decision model is to develop a structure for how CTOs make decisions. The decision-making structure is represented by a time-sequence diagram that abstracts all functions required to represent the cognitive map decisions. This diagram maps out the chronological sequence of activities that constitute the decision-making process, the conditions under which these activities occur, and their outcomes. During this process, all the functions in terms of input, process, and outcome were identified sequentially.

Data Collection

Primary data were collected through semi-structured interviews, a method effective for eliciting rich, nuanced information while allowing flexibility to probe emerging themes.[30] Interview questions focused on the CTO's role in technology strategy, decision-making processes, risk considerations and tool usage. A total of 14 in-depth interviews were conducted with CTOs from various industries including logistics, finance, telecom, manufacturing, power systems, and digital platforms. Interviews were recorded, transcribed, and anonymized in accordance with ethical guidelines. The study synthesized insights from interviews with expert CTOs to identify core decision patterns, leading to the framework of a cognitive mapping-driven strategic decision support system. ATLAS.ti version 7 was used to visualize and explore relationships between concepts, codes and data segments. The software provides Networks feature for the creation of visual maps to illustrate the connection among various elements. It helped to explore and iterate complex relationships, identify central themes and organize the findings. Cognitive maps were created for individual interviews and later synthesized into an integrated Cognitive map.

The cognitive mapping approach enables the systematic identification of leverage points where decision support can most effectively enhance quality and speed of CTO's decision-making capability in high-technology environments. It visually organizes the elements in the map, which are demarcated into four distinct zones to reflect the logical flow of inputs, core processing functions, internal mechanisms, and decision outputs (Fig. 1). These zones are visually coded using colored borders for clarity and interpretive coherence. The first zone, highlighted in light pink, represents the inputs to the CTO's DSS. These inputs include key environmental and organizational triggers that influence strategic decision-making, such as queries from top management, technological change, dynamic market environments, and time-to-market pressures. These elements signal the need for decision intervention and form the context within which the CTO initiates the planning process. The second zone, shown in light blue, includes the core analytical functions of the DSS. This section captures the cognitive and evaluative tasks undertaken by the CTO and the support system, such as assessment of technology, valuation of target acquisition, requirement of technological competencies, and assessment of effects on current and future systems. These functions constitute the analytical engine of the DSS, integrating technical, financial, and operational perspectives to assess the viability and implications of strategic choices. The third zone, highlighted in light yellow, denotes the processing mechanism of the DSS. It includes components like a platform to accept inputs and provide predictions based on decision-making modules and thorough analysis. These reflect the internal computational or inferential logic of the DSS—often supported by AI, predictive modeling, and expert systems—which processes the core analytical elements and translates them into actionable intelligence. The fourth zone, indicated in light green, presents the outputs of the CTO's DSS. These include strategic decisions and forward-looking actions such as formulation of technology strategy, five-year roadmap development, technology

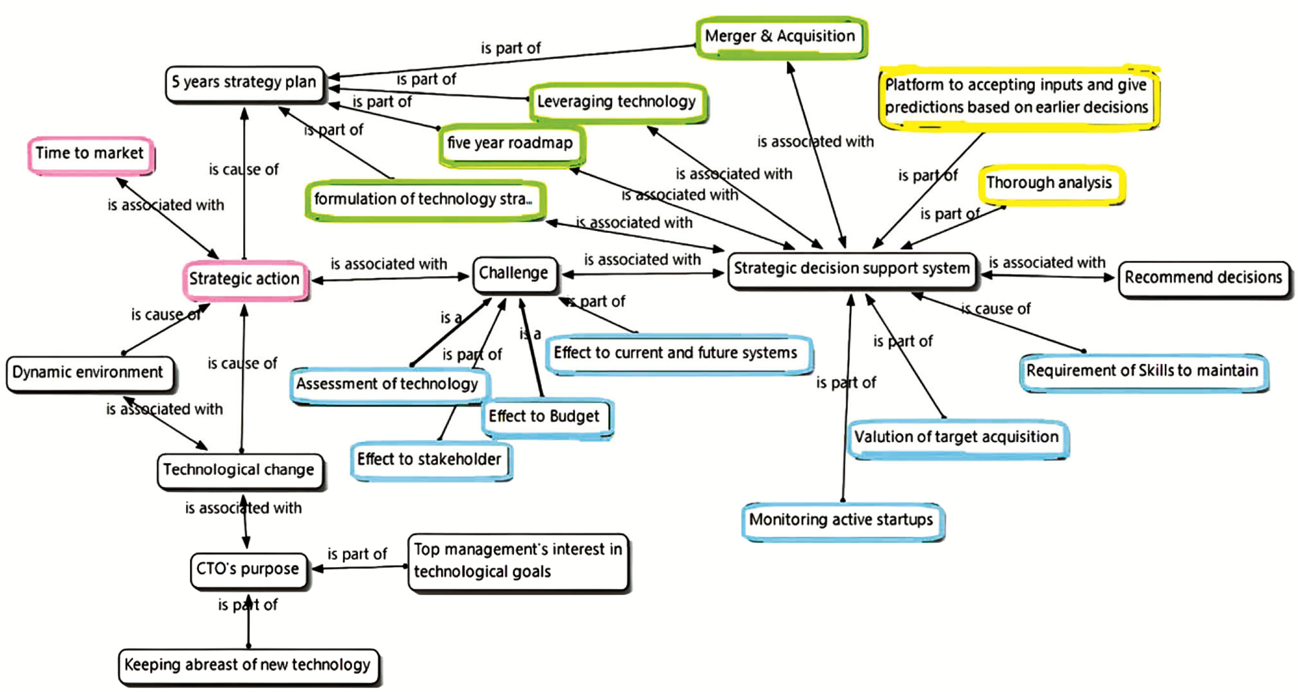

Fig. 1 — Cognitive Mapping of key elements in the Strategic Decision Support Framework for CTOs

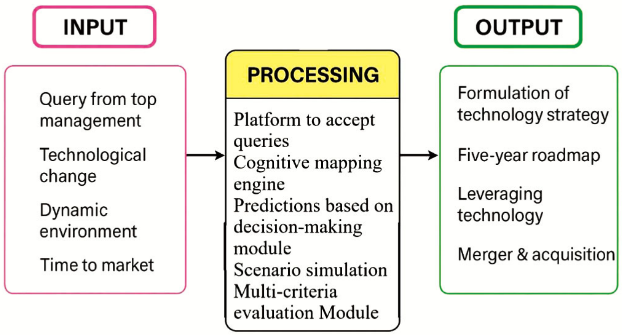

Fig. 2 — Proposed framework of SDSS for CTOs

leveraging, and merger and acquisition planning. These outputs not only guide technological investments and innovation priorities but also inform broader organizational strategies, reinforcing the CTO's evolving role as a strategic business partner.

Results and Discussion

Overall, the cognitive map demonstrates a sequential and modular decision-making process, beginning with strategic inputs, progressing through structured analysis and system-supported processing, and culminating in concrete strategic outputs. The interlinkages between elements reflect the dynamic and recursive nature of real-world decision environments in technology-led organizations.

Based on the identified themes and the cognitive mapping analysis, the proposed SDSS Framework is organized into three subsystems (Fig. 2): input, processing, and output.

The input subsystem gathers essential data required to initiate strategic analysis. This includes real-time internal metrics such as project status and resource availability, as well as external intelligence covering emerging technologies, startup ecosystems, and market trends. Additionally, it captures stakeholder expectations and strategic directives from leadership. The processing subsystem forms the analytical core of the framework. It incorporates a cognitive mapping engine to represent the structure of strategic decisions and their interdependencies. This is complemented by predictive modeling and scenario simulation capabilities—such as "what-if" analyses—that allow CTOs to anticipate possible outcomes. The subsystem also supports multi-criteria evaluation to assess technology options based on risk, strategic alignment, and Return On Investment (ROI). Finally, the output subsystem delivers actionable insights, including strategic recommendations aligned with business objectives, forecasts of skill and resource requirements, and validation of technology roadmaps. It can also provide targeted decision support for mergers, acquisitions, and other major investment activities, ensuring the CTO is equipped with a comprehensive, forward-looking view of technology strategy.

To illustrate the practical application of the proposed SDSS for CTO, a case of mid-sized financial services company is considered. Its CTO evaluates whether to invest in launching an artificial intelligence (AI)-based customer analytics platform. The decision involves multiple strategic, technological, and organizational considerations, which are processed through the SDSS framework (Fig. 2). The input stage receives a range of triggers. These include a query from the CEO regarding the potential for AI to enhance customer retention and cross-selling, recent technological advancements in open-source AI models, competitor actions involving similar tools, and internal time-to-market pressures from business stakeholders seeking deployment within a four to six month time durations. These inputs serve as decision catalysts and are captured by the SDSS to initiate further analysis. The processing stage relies upon the embedded analytical modules (each aligned with the cognitive components derived from expert interviews. Technology assessment module evaluates the potential acquisition of a startup offering a pre-built AI engine, assessing both cost and strategic fit. Simultaneously, the system identifies internal capability gaps in AI and suggests pathways for talent acquisition or upskilling. It further simulates the performance implications of integrating the AI engine into the company's legacy Customer Relationship Management (CRM) system. A predictive modeule, based on prior decisions and data inputs, estimates return on investment, implementation risks and likely uplift in customer retention metrics. The output stage generates a set of strategic recommendations such as licensing the externa AI module while customizing additional features in-house. The system updates the company's five year technology roadmap for phased rollout of new AI enabled CRM. These outputs are presented by the CTO to senior leadership, providing a clear, evidence based decision pathway. This example demonstrates how the SDSS consolidates diverse and dynamic information into structured decision support. It not only enhaces the speed and quality of strategic technological decisions but also ensures alignment with business objectives, resource constraints, and organizational readiness. It reflects the value of a cognitive-mapping driven SDSS in replicating the decision logic employed by modern CTOs operating in complex, high-velocity environments.

Conclusions

This study developed a cognitive mapping–based Strategic Decision Support System (SDSS) framework tailored for Chief Technology Officers (CTOs). Based on cognitive maps from qualitative analysis from of CTOs, the proposed model systematically integrates environmental inputs, core analytical functions, and decision outputs to support strategic technology planning. The study contributes both methodologically—by applying cognitive mapping in a strategic technology context—and practically, by offering a generalizable framework for CTOs across industries. However, the study is limited by its qualitative scope and the contextual diversity of the participating organizations. Future research could validate the framework through quantitative assessment or simulation-based testing. The SDSS framework can be applied by organizations seeking to formalize their technology decision-making processes, particularly in volatile and innovation-driven sectors. Its structured yet adaptable design supports predictive planning, investment prioritization, and capability evaluation in strategic technology management.

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