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A Review of Engineering Leadership Concept: A Way Forward

Alim Maktar[1], Khairun Nisa Khairuddin[1,2,*], Ummi Naiemah Saraih[1,2]

[1]Universiti Malaysia Perlis, Malaysia
[2]Center of Excellence for Social Innovation and Sustainability, Universiti Malaysia Perlis, Malaysia

*Corresponding author: nisa@unimap.edu.my

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ABSTRACT

Leadership is a critical component in business management, and in some situations, it can be vital to the survival of a company or organization. The concept of leadership has been extensively studied across various disciplines, yet the specific domain of engineering leadership remains underexplored and poorly defined. Every engineering organization, regardless of size, requires leaders and employees to execute projects to ensure their organization's success. This review article examines the existing definitions of leadership and engineering leadership, highlighting the lack of consensus in the field. By analyzing current literature, the authors identify the key attributes and skills associated with engineering leadership and discuss their relevance to contemporary engineering practices. Our findings reveal a fragmented understanding of engineering leadership, underscoring the need for further empirical studies to develop a cohesive and comprehensive definition. This article aims to provide a foundational understanding of engineering leadership and proposes directions for future research to bridge the gaps in the current knowledge, thereby paving the way for the development of robust theoretical and practical frameworks in engineering leadership. This paper focuses on leadership in the engineering context as the engineering sector plays a vital role in addressing sustainable development on a local, national, regional and global level. The concept of engineering leadership is dynamic across countries and sectors, thus merits more attention from scholars to explore the dynamism of the concept.

Keywords: Engineering Leadership, Leadership, Sustainable Development

1. INTRODUCTION

"Engineering has always transformed the world for the better. It is as relevant and urgent as ever, and more engineers with the right skills are needed." (UNESCO, 2021)

The above statement alarms that engineers with the right skills are needed to bring transformation for the world's betterment. Engineers are expected to be involved in more than just the technical aspects of projects. The engineering industry is evolving, and engineers also frequently deal with leadership responsibilities. Working in project teams is becoming increasingly prevalent in businesses, despite the task always being dynamic and complex, requiring a depth and wide range of knowledge. Engineers nowadays must integrate business and technical skills with soft skills such as leadership skills. One of the most important things for many countries is to ensure that the countries have adequate engineering graduates who are capable in both technical and management to meet the needs of the economy. The needs for sustainable development also require a holistic review of engineering curriculum in universities to include the necessary skills that employers and organizations need to deal with the current complex situation and meet society's needs and demand (UNESCO, 2021).

Leadership is a critical component in business management, and in some situations, it can be vital to the survival of a company or organization. The study of leadership is considered to be a mature field. However, the study of leadership in engineering, known as engineering leadership, remains unclear (Schell, 2018). To date, there is no consensus regarding the definition of engineering leadership, even though the topic has been discussed extensively in both industry and academia (Schumann, 2010; Kendall, 2018, Schell, 2018).

The study of leadership has long history and can be traced starting with works by the ancient Greeks, Romans. Despite its lengthy history and expanding body of research, there is scarce evidence of an accepted definition of leadership (Schell, 2018). Even though there is no consensus on the definition of leadership among scholars, past studies also found that leadership is multifaceted. The findings also suggest that leadership is complex and needs to be defined within specific contexts. As a result, despite a lack of consensus across the area of leadership, the literature on leadership within specific disciplines (like engineering) tends to represent valuable findings to be explored.

Past studies reported that managing engineers is more complex than managing people in other professions (Laglera, Collado, & Montes de Oca, 2013; Robledo, Peterson, & Mumford, 2012). This is probably because managing these teams effectively requires both technical and social abilities due to the high degree of task interdependence, the diversity of expertise necessary, the depth of individual competence required, and the high level of task interdependence.

This paper aims to assemble definitions that may accommodate a variety of perspectives and provide a stronger foundation for the study of engineering leadership. The task is challenging but worthwhile in understanding the concept clearly. Even if the proposed definition ends up being one of the numerous definitions that have already been proposed, the process of developing the definition may contribute to a deeper understanding of the concept of engineering leadership.

1.1 Emergence of Leadership in Engineering Context

Engineering is a crucial sector in meeting fundamental human needs, ensuring secure and sustainable development, reacting to emergency circumstances, providing safe infrastructure and encouraging society wellbeing. Engineering as a sector that bridge the gap between social requirements, technical innovation and business solutions to meet society demand. As a result, engineering is a significant factor in promoting sustainable socioeconomic growth. It has helped us become more resilient in facing natural disasters and threats to public health, as well as improve our access to food and water, communication and transportation.

Every engineering organization, regardless of size, requires leaders and employees to execute projects to ensure their organization's success. Engineers are employed to solve complex problems, conduct extensive analyses of processes, systems and structures, design, and develop and implement new systems (Reeve, 2010). The top qualities executives look for in candidates, after industry-specific experience and functional/technical expertise, are leadership skills, which are in great demand and sought after in candidates for both high-level and entry-level professional roles. According to Bragger et al. (2021), leadership is a skill that must be developed and practiced.

Furthermore, according to the National Academy of Engineering (NAE) (2019), in its recent report asserted that engineers must comprehend the principles of leadership and be able to apply it to a greater extent as their careers progress. Due to the growing interdependence between technology, economic and social in our modern society, engineers must possess and demonstrate leadership qualities (NAE, 2019). In addition, engineers must have both technical and soft skills in order to be true engineering leaders, which would offer them an advantage at work.

Russell and Yao (1996) noted that "an engineer is hired for her or his technical skills, fired for poor people skills, and promoted for leadership and management skills". This statement shows the importance of leadership and management skills in an engineer's career.

According to Laglera, Collado, & Montes de Oca (2013), not all professions are equally receptive to different leadership styles. This paper focuses on engineers since it has been demonstrated that those who undertake intellectually demanding work are far more receptive to leadership style than those who perform repetitive or administrative tasks. A report published by UNESCO (2021), Engineering for Sustainable Development: Achieving the Sustainable Development Goals, discusses the various sectors of engineering in which engineers may contribute to achieving the 2030 Agenda and the SDGs. UNESCO (2021) demonstrates the engineering profession's relevance in addressing the sustainability challenge. Engineering capacity and leadership competency development efforts are crucial for assuring an adequate number of engineers capable and willing to work on global challenges.

2. LITERATURE REVIEW

Rottman et al. (2105) described what constitutes appropriate leadership behaviours necessary for successful engineering business remains vague. This is due to an inadequate understanding of the concept of engineering leadership related to the role of engineering leaders who face new challenges and complexities of the project. The concept of leadership in engineering has its own body of specialized literature (e.g., Mallette, 2005; Mumford, 2000; Robledo et al., 2012). In order to develop a leadership framework within engineering context, Robledo et al (2011) emphasized the dynamism of project stages based on Mumford's work. Mumford and his colleagues (Byrne, Mumford, Barrett, & Vessey, 2009) proposed five stages through which creative projects progress as follows:

i. Scanning or initial exploration,
ii. Elaboration or data gathering, concept formulation, and gap identification,
iii. Development or formation, testing, and refinement of initial models,
iv. Appraisal or assessment of limitations, impacts, and benefits, and
v. Implementation or production and fielding of new products.

The following section discusses two crucial concepts -- leadership and engineering leadership.

2.1 Definition of Leadership

There are numerous definitions of leadership available in the literature. Despite its common usage, leadership is used in different disciplines to mean different meanings. Since the definition of leadership varies among researchers, it is important to clarify how the terms of leadership has evolved, particularly in engineering context. To begin, it is necessary here to clarify exactly what is meant by leadership, then followed by engineering leadership.

Stogdill's (1950) definition of leadership emphasizes that it is a process of influencing the activities of an organized group to achieve goals. This definition highlights the critical role of influence in leadership. Leaders use their ability to affect the behaviors, attitudes, and actions of their followers to steer the group towards specific objectives. This influence can manifest in various forms, such as communication, persuasion, and setting an example. It's not just about issuing directives but also about inspiring and motivating the group to align their efforts with the group's goals.

Moreover, the definition by Stogdill's (1950) underscores the importance of goal setting and achievement in leadership. Leaders are responsible for defining clear, achievable goals and ensuring that the group's activities are directed towards these goals. This involves strategic planning, decision-making, and problem-solving to navigate challenges and make necessary adjustments. Leadership is not a solitary act but occurs within the context of an organized group with established structures and roles. Effective leadership ensures that the group works cohesively towards common objectives, thereby achieving success through a collaborative effort. This approach to leadership is applicable across various contexts, including business, education, and community organizations, where aligning group activities with clear goals is essential for achieving desired outcomes.

The definition provided by Tannenbaum, Weschler, and Massarik (1961) describes leadership as the process of interpersonal influence exercised within a specific situation, directed through communication toward achieving particular goals. This highlights that leadership is fundamentally about influencing others, not just through authority, but through engaging and persuading them. The context or situation in which leadership is exercised plays a crucial role, as different circumstances may require different approaches. Effective leaders are those who can adapt their style to fit the situation, whether it be a crisis or a period of stability, thereby making their influence more impactful.

Furthermore, the emphasis on communication underscores its importance in the leadership process. Effective communication is the tool leaders use to convey their vision, provide direction, motivate, and build relationships. This involves both verbal and non-verbal methods, ensuring that the message is clear and the goals are understood. Leadership, therefore, is goal-oriented and purposeful, aiming to guide and coordinate efforts towards achieving specific objectives. By combining these elements—interpersonal influence, situational awareness, and effective communication—leaders can effectively steer their teams toward the attainment of set goals, demonstrating the multifaceted nature of leadership.

Kotter's (1988) definition of leadership as "the process of moving a group (or groups) in some direction through mostly non-coercive means" emphasizes the essence of leadership as a guiding and influencing role rather than one based on force or authority. This view of leadership underscores the importance of persuasion, inspiration, and motivation rather than coercion. Leaders, according to this definition, are those who can effectively guide their teams or organizations toward a desired direction or goal by fostering cooperation and commitment rather than imposing directives.

In practice, this means that effective leaders rely on their ability to communicate a compelling vision, build trust, and engage others through mutual respect and understanding. They use their influence to align the group's efforts with the desired direction, leveraging their interpersonal skills to inspire and motivate. This non-coercive approach fosters a more positive and collaborative environment, where team members are more likely to be committed and invested in the collective goals. By moving the group through influence rather than force, leaders can achieve sustainable and meaningful progress, encouraging innovation and creativity within the team. Kotter's definition highlights the relational and ethical dimensions of leadership. It suggests that true leadership lies in the ability to inspire and mobilize people through positive and constructive means, creating a shared sense of purpose and direction. This approach not only enhances the effectiveness of the team but also builds a foundation of trust and respect, which are essential for long-term success and resilience.

Bass's (1990) definition of leadership describes it as an interactive process among group members, where the dynamics often involve structuring or restructuring situations, as well as shaping the perceptions and expectations of the group. This perspective emphasizes that leadership is not a one-way street but a reciprocal and dynamic interaction. Leaders and

followers influence each other, creating an evolving environment where the situation and goals can be continuously redefined. This interaction helps in adapting to changing circumstances and ensuring that the group's efforts are aligned with the desired outcomes.

Moreover, Bass (1990) highlights that leadership involves modifying the motivation or competencies of group members, indicating that effective leaders can inspire, empower, and develop their team. Importantly, he asserts that any group member can exhibit leadership, suggesting that leadership is not confined to those with formal authority or titles. This democratic view of leadership recognizes that influence can come from various sources within the group, and different members can step up to lead based on their strengths and the needs of the situation. This inclusive approach fosters a more collaborative and adaptive environment, where leadership potential is distributed and can emerge organically from within the group.

Bennis and Townsend's (1995) definition of leadership as "the capacity to create a compelling vision and to translate vision into organizational realities" emphasizes two critical aspects of effective leadership: visionary thinking and practical implementation. This vision provides direction and purpose, serving as a guide for decision-making and actions within the organization. It is not just about having ideas but about communicating them in a way that resonates with others and fosters a shared sense of purpose. Translating vision into organizational realities underscores the importance of execution in leadership. A leader must not only inspire but also ensure that the vision is implemented effectively. This involves strategic planning, resource allocation, and motivating the team to take concrete steps toward achieving the vision. It requires a combination of strategic thinking and operational expertise to bridge the gap between the conceptual and the practical. Effective leaders can navigate challenges, adjust plans as needed, and keep the organization focused on its goals, turning visionary ideas into tangible outcomes. This definition highlights that true leadership lies in the ability to both inspire and execute, making visionary ideas a reality within the organizational context.

Drucker's (1996) definition of a leader as "someone that has followers" focuses on the fundamental relationship between leaders and followers. This definition underscores that leadership is inherently relational; it is not about titles, positions, or personal attributes alone, but about the ability to attract and retain followers. A leader is someone who others choose to follow, which implies a level of trust, respect, and influence. This view simplifies the concept of leadership by emphasizing that the true measure of leadership is the presence of followers, as leadership without followers is ineffective and inconsequential. By highlighting the importance of followers, Drucker's definition shifts attention to the dynamics of influence and the reasons why people choose to follow a leader. It suggests that leaders must earn their followers' support through their actions, vision, and behavior. This perspective encourages leaders to focus on the needs, motivations, and engagement of their followers, recognizing that their ability to lead is directly linked to their capacity to inspire and motivate others. It emphasizes that effective leadership is not about exerting control but about cultivating a supportive and committed following, which is essential for achieving any collective goal or vision.

Kellerman's (2015) definition of leadership as a system with three interdependent parts—the Leader, the Follower, and the Context—emphasizes the complexity and dynamic nature of leadership. This systemic view suggests that leadership cannot be fully understood by focusing on just one element in isolation; instead, it requires examining the interactions and relationships between all three components. The leader's actions, characteristics, and decisions are crucial, but equally important are the followers who respond to and interact with the leader. Followers' needs, perceptions, and behaviors significantly influence the effectiveness of leadership.

Moreover, the context, or the environment in which leadership occurs, plays a critical role. The context includes cultural, social, economic, and organizational factors that can shape the leadership process. It affects both the leader's strategies and the followers' responses. For instance, leading a team in a startup environment may require different approaches compared to leading in a well-established corporation. This definition underscores that leadership is situational and contingent, relying on the dynamic interplay between leaders, followers, and the context. Effective leadership, therefore, requires a nuanced understanding of how these three elements influence each other and adapting accordingly to achieve desired outcomes. Table 1 summarizes the definition of leadership.

Table 1 Definition of Leadership

Author (Year)	Definition
Stogdill (1950)	"The process (act) of influencing the activities of an organized group in its efforts toward goal setting and goal achievement".
Tannenbaum, Weschler & Massarik (1961)	"Interpersonal influence, exercised in a situation, and directed, through the communication process, toward the attainment of a specified goal or goals"
Kotter (1988)	"The process of moving a group (or groups) in some direction through mostly non-coercive means"
Bass (1990)	"Leadership is an interaction between two or more members of a group that often involves a structuring or restructuring of the situation and the perceptions and expectations of members…Leadership occurs when one group member modifies the motivation or competencies of others in the group. Any member of the group can exhibit some amount of leadership…".
Bennis & Townsend (1995)	"The capacity to create a compelling vision and to translate vision into organizational realities"
Drucker (1996)	"The only definition of a leader is someone that have followers"
Kellerman (2015)	"Leadership as a system consisting of three moving parts, each of which is equally important and each of which impinges equally on the other two. The first is the Leader. The second is the Follower. And the third is the Context."

Scholars have proposed numerous definitions of leadership in the 20th century. The definitions above also demonstrate how the idea of leadership has changed over time. Silva (2016) points out that the proposed definitions make it possible to comprehend what leadership is, but it does not describe good or bad leadership or effective or ineffective leadership. Toward the end of the 20th century, Drucker (1995) summarized the idea of leadership by emphasizing that "the only definition of a leader is someone that have followers". One of the contemporary thinkers in the 21st century, Kellerman (2015) further extend the perspective of leadership by adding the component of context as an equally important to leadership and followership. According to Kellerman (2015), leadership is different today than it was five, ten, or twenty years ago. It also differs across context and countries. Kellerman (2015) also asserted that the leadership will be different if the context evolved. Therefore, leadership in the context of engineering also could be something different and merit further attention.

2.2 Definition of Engineering Leadership

There are many engineering leadership development programmes have been formed globally in response to the demand for engineering graduates with greater leadership abilities. However, there seems to be a lack of clarity in defining engineering leadership and explaining how it varies from general leadership (Paul, 2018).

Shaw's (2002) definition of engineering leadership emphasizes the comprehensive process involved in creating new products and services. It highlights the need for envisioning, designing, developing, and supporting these offerings in alignment with a set of requirements. This process must be conducted within the constraints of budget and schedule while managing acceptable levels of risk. This definition underscores the importance of strategic alignment, where engineering leaders ensure that their projects support the broader objectives of the organization. It reflects the multifaceted role of engineering leaders in balancing technical expertise with strategic planning, risk management, and resource allocation to deliver successful outcomes.

Crumpton-Young et al. (2010) define engineering leadership as the ability to lead a diverse group of personnel in the creation, design, development, implementation, and evaluation of products, systems, or services. This definition emphasizes the collaborative nature of engineering leadership, where leaders must integrate and manage contributions from individuals with varied profiles and expertise. It highlights the necessity for engineering leaders to possess strong interpersonal and team management skills, enabling them to coordinate efforts across different disciplines to achieve common goals. The focus on the entire lifecycle from creation to evaluation suggests that engineering leaders must be adept at both initiating projects and ensuring their successful completion.

Northouse's (2010) definition positions engineering leadership within the context of managing technical change and fostering innovation. It emphasizes the conception, design, and implementation of solutions supported by enabling technologies to meet customer and societal needs. This definition highlights the role of engineering leaders in driving technological advancements and managing the complexities associated with innovation. It underscores the importance of creativity and technical expertise in developing new solutions and the need for leaders to stay attuned to the evolving needs of customers and society. Engineering leaders are seen as visionaries who guide technical teams in turning innovative ideas into practical applications.

The National Society of Professional Engineers (NSPE, 2010) definition highlights several key traits of engineering leadership, including risk assessment, decision-making in uncertainty, urgency, resourcefulness, flexibility, and the ability to build trust and loyalty within a team. This definition underscores the critical qualities required for effective leadership in engineering contexts, where projects often face constraints and unforeseen challenges. It suggests that engineering leaders must be proactive, decisive, and resilient, capable of navigating obstacles while maintaining team cohesion and morale. The emphasis on interpersonal skills and team dynamics indicates that successful engineering leadership also depends on the leader's ability to relate to and motivate others.

Al-Sagheer (2011) defines engineering leadership as the ability to guide entire projects and influence others to meet schedules and quality requirements within specified time and budget constraints. This definition emphasizes the project management aspect of engineering leadership, where leaders are responsible for ensuring that projects are completed on time, within budget, and to the satisfaction of customers. It highlights the importance of influence and guidance, suggesting that engineering leaders must be skilled at motivating and directing their teams to achieve project goals. The focus on customer quality requirements also underscores the need for leaders to maintain high standards and ensure that the final deliverables meet or exceed expectations. Table 2 summarizes the definition of engineering leadership.

Table 2 Definition of Engineering Leadership

Author (Year)	Definition
Shaw (2002)	"Engineering (leadership) is the process of envisioning, designing, developing, and supporting new products and services to a set of requirements, within budget, and to a schedule with acceptable levels of risk to support the strategic objectives of an organization."
Crumpton-Young et al. (2010)	"The ability to lead a group of personnel from various profiles for creating, designing, developing, implementing, and evaluating products, systems, or services"
Northouse (2010)	"Management of technical change, innovative conception, design, and implementation supported by the invention of enabling technologies to meet the needs of customers and society."
NSPE (2010)	"The ability to assess risk and take initiative, the willingness to make decisions in the face of uncertainty, a sense of urgency and the will to deliver on time in the face of constraints or obstacles, resourcefulness and flexibility, trust and loyalty in a team setting, and the ability to relate to others."
Al-Sagheer (2011)	"The ability of the leader to guide the whole project and influence other people to meet the schedules and customer quality requirements while working within specified time and budget constraints."

From the definitions above, engineering leadership encompasses a comprehensive and multi-faceted role. Engineering leaders are responsible for the entire lifecycle of projects, from envisioning and designing to developing and supporting new products and services, all while managing budgets, schedules, and risks. Effective leadership in this field requires the ability to integrate and lead diverse teams, demonstrating strong interpersonal and team management skills. Additionally, engineering leaders play a crucial role in driving innovation and managing technical change, ensuring that new technologies meet the evolving needs of customers and society.

However, due to confusion in explaining the engineering component in engineering leadership and articulating key differences between general leadership and engineering leadership, several scholars have explored the concept of engineering leadership (Paul, 2018, Kendall et al., 2018). Past researchers also suggested that a more holistic and integrated engineering leadership model would provide insightful understanding in helping leaders within the engineering context.

3. CONCLUSION AND WAY FORWARD

Past studies demonstrate that the concepts of leadership are commonly categorized into distinct models or styles. There are numerous definitions of leadership, with many leadership models and attributes available in the literature. However, as asserted by Kellerman (2015), in understanding leadership, it is paramount important to consider the context in which the leadership process occurs. This paper focuses on leadership in the engineering context as the engineering sector plays a vital role in addressing sustainable growth on a local, national, regional and global level. The concept of engineering leadership is dynamic across countries and sectors, thus merits more attention from scholars to explore the dynamism of the concept. It is suggested that future research can explore the concept of engineering leadership among engineering leaders in specific countries.

The leadership of engineers is complex in part because it calls for a diverse set of abilities and knowledge, and the specific requirements for these qualities can shift at various points throughout the creative process. For instance, having knowledge and experience concerning the organization, having technical abilities, and having a strong group all appear to be essential components of leading creative endeavours. Given the necessity of having a diverse set of talents, one possible area of focus for research in the future could be on many forms of leadership. For instance, organizations may recruit multiple leaders to compensate for each other in terms of lacking competence in required areas by teaming up with one another. In this scenario, effective communication amongst leaders is likely to be of the utmost importance to enable many leaders to work together as a unified entity toward achieving corporate goals. Certain topics, such as the various ways of defining and sharing leadership roles, coordinating activities, developing shared mental models of leadership and followership, and investigating the influence of diversity on multiple leadership structures, may be deserving of further research. It is vital to analyze if the benefits of developing engineering leaders inside an organization outweigh the costs of doing so, whether those costs are monetary, time-related, or some other kind. This is a practical aspect that should be taken into account.

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