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Strategic roadmapping of robotics technologies for the power industry: A multicriteria technology assessment

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ABSTRACT

This paper presents an application of a strategic technology management tool in the power sector. Technology Development Envelope is an extension of hierarchical decision modeling and Analytical Hierarchy Process into the future. The process yields multiple paths for technology development enabling organizations to build roadmaps depicting their strategies. The focus of this paper is robotics technologies and their applications in the power sector. As robotics technologies advance, they replace humans in very critical areas such as maintenance of transmission lines or hydro dams as well as operations in nuclear power plants. A decision model was developed and quantified through this study. It is validated with a case study from Electric Power Research Institute (EPRI) reflecting their priorities. The model establishes a framework that any other organization can adopt and use to evaluate any emerging robotics technologies.

1. Introduction

Electricity is a fundamental public commodity for the welfare of the general public, and for sustaining the economy. Therefore, electric power utilities as important infrastructures should be operated stably without any failure in supply of electricity. For example, the Northeast blackout of 2003, which was an unexpected power outage throughout Midwestern and Northeastern United States and some Canadian regions caused countless amount of financial and social loss (*U.S.-Canada Power System Outage Task Force,* 2006). Therefore, for stable operation, it is necessary to input huge amount of resources and investment throughout power generation, transmission, and distribution facilities. Particularly, constant inspection and maintenance of the facilities requires highly skilled manpower and advanced technologies.

However, in spite of endless efforts, the electric power industry is facing serious challenges from social, economic, and environmental problems. In general, the working environment of electric power facilities includes hazardous conditions such as high voltage, high temperature, high density of electromagnetic field, and radiation. Therefore, alternative technologies that are available to carry out various tasks under these hazardous conditions, instead of human workforce, are indispensable (Park et al., 2012; Parker and Draper, 1998). In addition, the operation of electric power facilities is facing an ever-intensifying shortage of manpower due to aging population and the retirement of skilled people. According to Allen, electric power industries are aware the seriousness of an aging population and the shortage manpower due to job changes or the retirement of skilled professionals (Allan, 2012; Liu and Wayno, 2008). Furthermore, the strengthening of human safety related regulations encourages greater efforts for the prevention of industrial accidents, and for reinforcing safety technologies in electric power companies. Robotics technologies have been regarded as one of promising alternative technologies.

In this regard, a large amount of research and practical applications relevant to robotics technologies have been introduced in academia and the industrial world with a full-fledged distribution of industrial robotics. In practice, a number of robotic systems have been tested and applied for inspection and maintenance in nuclear power plants (Iqbal et al., 2012; Kim et al., 2010; Marinceu et al., 2012; Roman, 1993) and high voltage power transmission lines (Allan, 2012; de Oliveira and Lages, 2010; Elizondo et al., 2010; Lages and de Oliveira, 2012; Montambault and Pouliot, 2014; Montambault et al., 2012; Siebert et al., 2014; Wu et al., 2010). However, despite a variety of attempts, a lot of these efforts have not evolved beyond the R & D stages or have only been applied in limited areas in electric utilities (Allan, 2012). There are several reasons behind the slow dissemination of robotics technologies in the operation and maintenance of electric utilities. One

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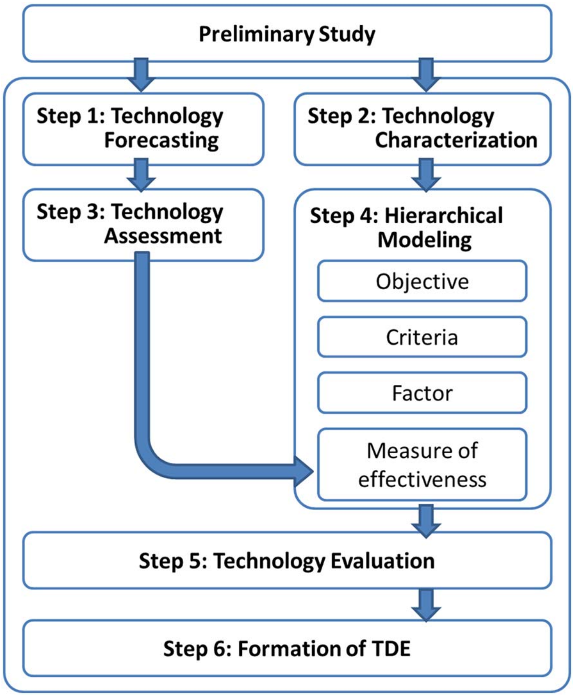

Fig. 1. Procedure of TDE formation.
(Source: Gerdsri, 2007).

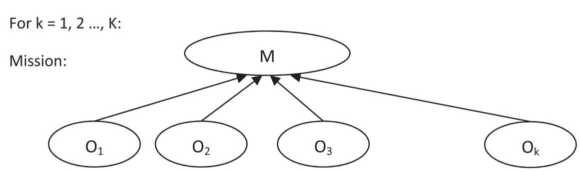

Fig. 2. HDM Structure.

of the reasons is that although the efforts and funding have been dispersed through all relative sectors, the key results of them have not been shared well with other sectors (*Program on Technology Innovation: EPRI State of Robotics—Assessment and Proposed Strategic Program*, 2013), which has lowered the efficiency of the funding.

This paper presents an analysis of available robotics technologies from the perspective of the power sector. The first stage of the analysis included identification of experts in the field through the integration of bibliometrics and social network analysis. The second stage utilized an approach based on hierarchical decision modeling to score technologies in multiple perspectives into the future. The results indicated that the concrete crawler robot is expected to have the highest benefit through 2020 while the snake robot will increase rapidly between 2015 and 2018. The transmission line robot technology will have gradual advancement, which will reach the highest benefit in 2022.

2. Literature review

In order to strengthen the technology management capability in organizations, technology assessment and forecasting is important in estimating potential technological changes. Tran and Daim (2008) and Daim and Kocaoglu (2008) provided a review of methods available for these purposes. Their results showed that choice of tool was dependent on the objective of technology acquisition as well as the type of the organization. Few tools support the technology assessment and forecasting of emerging technologies because most of the tools refer to historical data (Daim et al., 2006). In this case, qualitative methods such as Delphi and scenarios provide insights of future emerging technologies rather than other methods based on historical data.

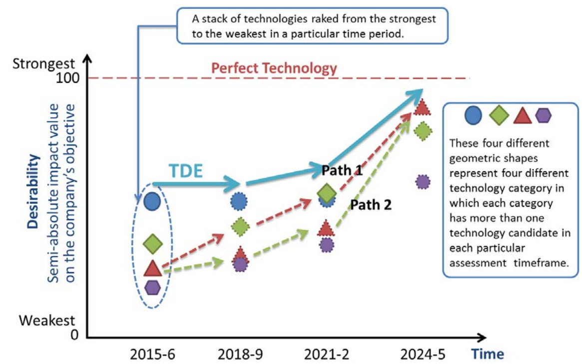

Fig. 3. TDE diagram.
(Source: Gerdsri, 2007).

Additionally, bibliometrics and patent analysis are useful for emerging technologies (Gerdsri et al., 2010b; Kajikawa et al., 2008b; Sasaki et al., 2010). With these various methods for technology management and planning, a lot of organizations strive against fierce competition of technological advancement (Daim et al., 2011).

In particular, technology roadmapping as a technology planning process supports developments of technological alternatives fulfilling product requirements or organizational objectives by identifying, selecting, and developing technology alternatives (Phaal et al., 2004). Nevertheless, according to Gerdsri (Gerdsri, 2007), although it is important to reflect various insights of either internal or external stakeholders in decision makings for technology forecasting and evaluation, few methods are capable of linking them. Also, while technology roadmaps are actively applied to establishing strategic plans among a variety of industries and organizations, it is somewhat difficult to update and revise technology roadmaps periodically due to the procedural nature of the methods (Daim et al., 2011; Gerdsri, 2007; Gerdsri and Kocaoglu, 2003).

3. Technology roadmapping

As reported by Phaal et al. (Phaal et al., 2011), technology roadmapping is a process that emerged from the industry and it is only natural that it is applied in the industry. The process has been improved by many researchers since its introduction (Amer et al., 2016; Gerdsri et al., 2009, 2010a; Phaal and Muller, 2009; Thorn et al., 2011). The new approaches demonstrated the integration of technology roadmapping with other tools to improve the value for the organizations. These tools included quantitative tools targeting to quantify the linkages or scenarios to explore possible alternative futures.

The approach is used in areas including energy (Amer and Daim, 2010; Daim et al., 2012a, 2012b, 2012c), business modeling (Abe et al., 2009), dual technology (Geum et al., 2013), services (Daim and Oliver, 2008; Geum et al., 2011; Martin and Daim, 2012), policy making (Yasunaga et al., 2009), customized roadmaps (Lee and Park, 2005), sustainable products (Petrick and Echols, 2004), disruptive technologies (Rinne, 2004), silicon industry (Walsh et al., 2005), foresight (Saritas and Oner, 2004), parts and materials industry (Lee et al., 2007), wood pellets (Lamb et al., 2012).

Many integrated other used approaches making roadmapping more effective including integration of science and technology indicators (Kajikawa et al., 2008a), evaluating disruptive threats and opportunities (Galvin, 2004; Kostoff et al., 2004; Vojak and Chambers, 2004), using data mining (Geum et al., 2015), integrating services and devices for smart cities (Lee et al., 2013), evaluation of success in the renewable energy sector (Jeffrey et al., 2013), transition management (McDowall, 2012), technology convergence (Yasunaga et al., 2009), communications theory (Lee et al., 2012), scenarios (Hansen et al., 2016), corporate foresight (Vishnevskiy et al., 2015), smart specialization