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Mapping Technological Dynamics as Keyword Co-occurrence Clusters: A Study on the Electrified Vehicles Research

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Abstract— **Since1990s, electrified vehicles (EV) have experienced a significant rate of growth marked by a continuing period of significant technological change. It is argued that the technological change have been taking place along ordered and selective patterns in the potential paradigmatic shift of EV evolution. A scientometric method has been proposed to map the technological dynamics instead of historical descriptive analysis. The methodology undertakes a keyword co-occurrence analysis of patents in the field of electrified vehicles.**

Index Terms— **keyword co-occurrence; technological dynamics; electrified vehicles research**

1. INTRODUCTION

Although patent indicators may miss many non-patented inventions and innovations[1], the use of patent information is gaining increasing attention in the fields of innovation and technology management for a very long time, for example, to measure technological change[2], to identify technological competences[3], technology life cycles[4] and networks among actors[5]. Patent data represent a valuable source of information that can be used to plot the evolution of technologies over time. This paper explores the value and use of patent keyword co-occurrence network to study the dynamics of technical change. We report the use of Derwent World Patent Index (Derwent) data to analyze responses to regulatory change in the automobile industry with the development of the electrified vehicle (EV).

The purpose of this paper is to understand the technological changes from internal combustion engine based vehicles (ICEV) to electric vehicles (EV) from the perspective of technological trajectory. The investigation will be conducted by signifying the methodology of patent data analysis. Based on the patent analysis, this paper will define technological competitive dynamics of EV technology in terms of knowledge flows within a patent keyword co-occurrence network.

2. ELECTRIC VEHICLE TECHNOLOGY

It is well recognized today that electric vehicle (EV) technologies are vital to the overall automotive industry, in terms of both better fuel economy and reducing vehicle emissions. Over the past decade, these technologies have taken a significant leap forward. Internal combustion engine vehicles (ICEV), referred to as traditional and conventional vehicles, are the primary vehicle drive method today and will remain so into the foreseeable future, but it is hypothesized that alternative fuel vehicles (AFV) will increasingly gain market share. AFV encapsulate a wide range of technologies that compete for innovation and infrastructure funding from the State. They include hydrogen fuel cell vehicles (HFC), coal-to-liquid (CTL), compressed natural gas (CNG), liquefied petroleum gas (LPG), combustion vehicles using bio-fuels (there are many types of bio-fuels), and others. Another subset of AFV is electric drive vehicles (EDV) or electrified vehicle referred to simply as electric vehicles (EV) in this paper, which include hybrid electric vehicles (HEV) , battery electric vehicles (BEV), and also plug-in hybrid electric vehicles (PHEV).

With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, electric, hybrid vehicles have attracted more and more attention by automakers, governments, and customers. Research and development efforts have been focused on developing novel concepts, low-cost systems, and reliable hybrid electric powertrain. The EV was invented in 1834. However, due to the limitations associated with the batteries and the rapid advancement in ICE vehicles, EVs have almost vanished from the scene since 1930. Nevertheless, in the early 1970s, some countries, compelled by the energy crisis, started the rekindling of interests in EVs. In 1990, California had a mandate on the use of zero emission vehicles. The world started down a new road in 1997 when the first modern hybrid electric vehicle (HEV), the Toyota Prius, was sold in Japan. Two years later, the U.S. saw its first sale of a hybrid, the Honda Insight. These two vehicles, followed by the Honda Civic Hybrid, marked a radical change in the type of car being offered to the public: vehicles that bring some of the benefits of battery electric vehicles into the conventional gasoline powered cars and trucks we have been using for more than 100 years. Along the

line over 20 models of passenger (H)EVs have been introduced to the auto market[6-8].

Electric vehicle is a multidisciplinary subject which covers broad and complex aspects. However, it has key technologies (components), namely, batteries and electrochemical capacitors, propulsion motor, power converters, hybrid control technology, and energy source & infrastructures.

3. THEORETICAL BACKGROUND AND RESEARCH FRAMEWORK

In our research, we present a methodology of patent keyword co-occurrence network analysis for studying the technological evolution in the EV industry. The methods were broadly adopted based on the hypothesis that patents represent technologies.

Patent data represent a valuable source of information that can be used to plot the evolution of technologies. There has been some discussion in the literature as to the reliability of patent data, but there is a consensus that patents granted in the US are at least indicative and possibly offer a good proxy for technological development [9-14]. Patent study illustrates how technological preferences have shifted over time [15]. The traditional approach to new car development is to re-style the body of an existing vehicle incorporating engines, gearboxes and components from other models with only minimal changes to the mechanics of the vehicle [16]. However, there are no existing power train or mechanical components to design the battery electric vehicle around and so the new product development process has to innovate these systems[17]. Xie and Miyazaki (2013) provide a principle of key words selection for patent identification. The results show that the most effective method of identifying patents in a specific domain through key word search is using the patent information in the title, abstract and claims. Furthermore, patent citation analysis can be further understood to combine social network analysis and patent metrics methods. Yoon and Kim [18] used SAO-based semantic patent network to identify the rapidly evolving technological trends for R&D planning, in which SAO, subject-action-object structure, represented the explicit relationships among components used in a patent, and was considered to represent key concepts of the patent or the expertise of the inventor. In this study, we will achieve the patent's co-occurrence in the network in order to expose the knowledge evolution and knowledge structure [19, 20].

The data is based on the patent database of Derwent World Patent Index (Derwent). Our approach rests mostly on keyword citation, cluster analysis and network analysis. In order to highlight the intellectual base and research fronts of electric vehicle, CiteSpace which was developed by Professor Chen from Drexel University was applied to do the document co-citation analysis. The whole process contains two procedures: one was data pre-processing to acquire keywords co-occurrence matrix; the other was cluster analysis produced with software CiteSpace[21-23]. The function of spectral clustering with automated keywords-label will implement in this paper. Derwent manual code (DMC) in DII highlights the inventive and significant aspects of the invention, and it is drawn from patent specification by technical scholars to reveal its technical detail and its technology innovation. So Derwent manual code is analogous to the keywords in scientific papers.

We identified 58837 patents in Derwnet database using keyword search from 1970 to 2013. (see Fig.1).

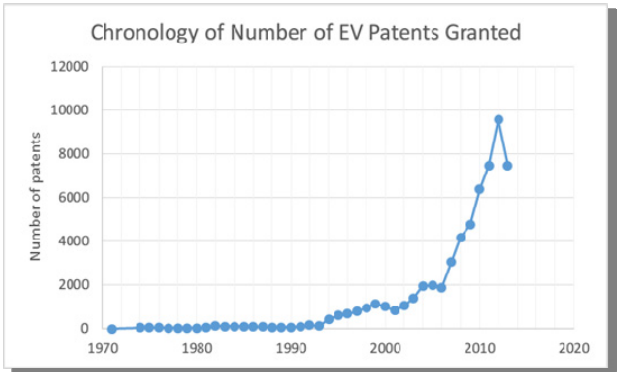

Fig 1. Chronology of Number of EV Patents Granted

Importing the keyword co-occurrence matrix to CiteSpace, the software produced the co-occurrence map shown in Fig.2.

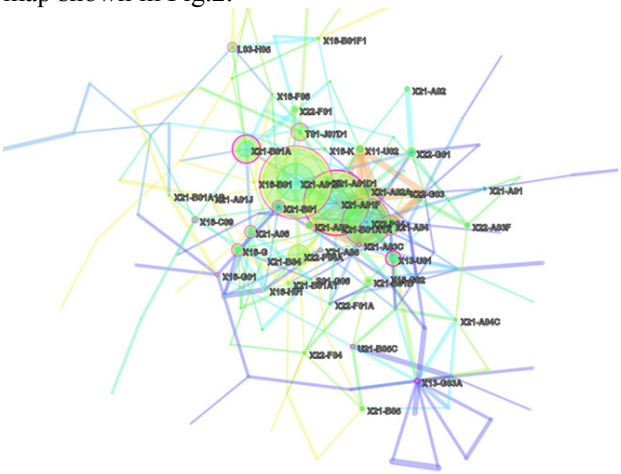

Fig 2. Cluster of the Derwent MC co-occurrence Visualization of the EV Patents

In the visualization of the keyword co-occurrence network shown in Fig.2, nodes represent Derwent manual code and lines represent keywords co-occurrence which were the basic elements making

Categories	Derwent manual code	Technological characteristics
Battery	X22-F01A,X22-F01,X21-B01A1C,X21-B01A1A,X21-B01A1,X21-B01A,X21-B01,X21-A06,X16-K,X16-H03,X16-H01,X16-H,X16-G02,X16-G01,X16-G,X16-F06A,X16-F06,X16-C09,X16-C,X16-B01F1,X16-B01,S01-G06A,S01-G06	Batteries chargers and charging control; On/Off-board Charging arrangements; Measurements and testing; Battery cooling, heating; Remaining charge; Chargers Using ac mains or other sources; Battery packs; Lithium-based;
Control of vehicle	X22-A03F,X21-A05, X13-U01	engine management; Safety; monitoring; instrumentation; Switchgear, protection application;
Electric Controlling	X21-A04, X21-A03C, X21-A04C,X13-G03A,L03-H05, X13-G01,X13-F02	Traction motor speed control; Electrodynamic; Inverter control; Speed or torque of electric motors; Stopping or slowing electric machines; sparking and resistive ignition plugs
Electric Propulsion	X21-B01B,X21-A07,X21-A02, X21-A02A,,X21-A01, X11-U02,V06-U03	Transmission system and its control; Electric traction motor; Mounting of propulsion units; gearing; Electric propulsion; Electric Power generation
Power supply and related aspects	X22-G03,X22-G01,X22-F04,X21-B05,X21-B04, U21-B05C	Powertrain/transmission control systems; Transmission/clutch/gear systems; power supply control systems; Power converter; power switching ;Combination of battery and other source;
ICT related	T01-J07D1	Vehicle microprocessor system (Data processing systems)

Table.1. the technological dynamics in the patents of EV industry

concordance between network properties and technology evolution mechanisms. Particularly, the colour of the line corresponded to the year of co-occurrence, which could be used as a visual statement of technology evolution.

4. RESULT

For the whole datasets, we split the patents into 8 slices from 1990 to 2013 with every 3years a slice, and then select top 50 most occurrence keywords from each slice to complete the further analysis. In the cluster analysis, the keywords (DMCs) of co-occurrence frequency more than 100 were chose for identifying the technological dynamics. From the cluster of the DMC co-occurrence visualization of the EV Patents in Fig.2, in conjunction with the co-occurrence frequency on the whole, the technological dynamics of EV from 1990 to 2013 could be divided into six categories list in Table 1.

This paper mainly discussed the methodology of mapping technological dynamics as keyword Co-occurrence clusters in EV patent filed which represent the technology, not mentioning scientific papers which represent science pole and modeling the interaction between science and technology in EV research. Such kind of research topics will be discussed in our future study.

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