An Analysis of Bogie Technology Development: Based on Patent Generational Citation Tree

Abstract: This paper uses patent generational citation tree to explore the development of bogie technology, which is one of the core technologies of high speed rail. First of all, the patent citation information is used to explore the generational development tree of bogie technology. Later, we shall dig three aspects of information closely related to the technology development, including patent titles, patent publication dates and patent granted regions. It is on this basis that the bogie technology development is analyzed from three respects, including technology development path, technology life cycle and technology regional diffusion. Our results show that the development of bogie technology is precisely on the path and the main path is clear. The technical life cycle is still in the stage of growth, while the spread of technology is somewhat lacking and lagging in terms of scope and speed. Finally, we draw upon the sampling method to select a complete reference chain to verify relevant results.

Key words: patent citation tree; bogie technology; technology development path; technology life cycle; technology regional diffusion

Introduction

The development of technology is retraceable and the patent citation network is an intuitive presentation, which is thus capable of showing the history of technological development process. Therefore, in accordance with the citation relationship generated by the patent citation network, we can analyze the development of specific technology, like studying the history of technology development, carrying out technical evaluation, path selection and activity forecasting, etc. The development evolution of bogie technology can help to sort out its development history, reflecting the present status and providing a reliable basis for exploring its future development.

Bogie technology is one of the core technologies in the field of railways. The main types of bogies can be divided into motor and track bogies based on power, or divided into two-axis, three-axis and multi-axis bogies based on axis' count, or divided into pull-type, rod-type, arm-type, laminated, dry friction bogies based on axial positioning mode. Different bogies are designed for different speeds, loads and power requirements, all of which have special and general traits. The research target of this paper is general bogie technology and the typical bogie image can be illustrated as Figure 1.

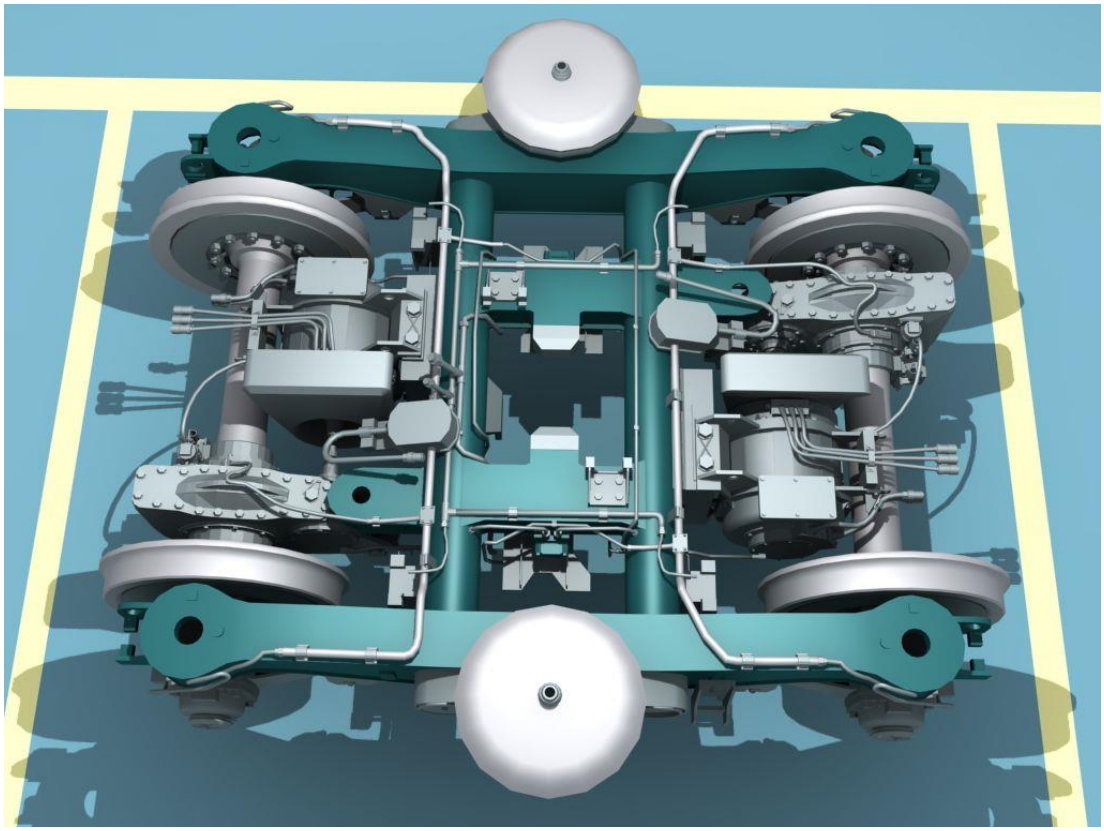


Figure 1 Drawing of typical bogies[1]

Specifically, for the three types of bogies（shown in Figure 2）. Respectively, named bogie A, bogie B and bogie C. They each have their own technologies (special traits, the part not cross), but also have some common technologies (common traits, two-two cross or three cross each other). The research techniques of this paper are their common sections, which means $A \bigcup B \bigcup C$.

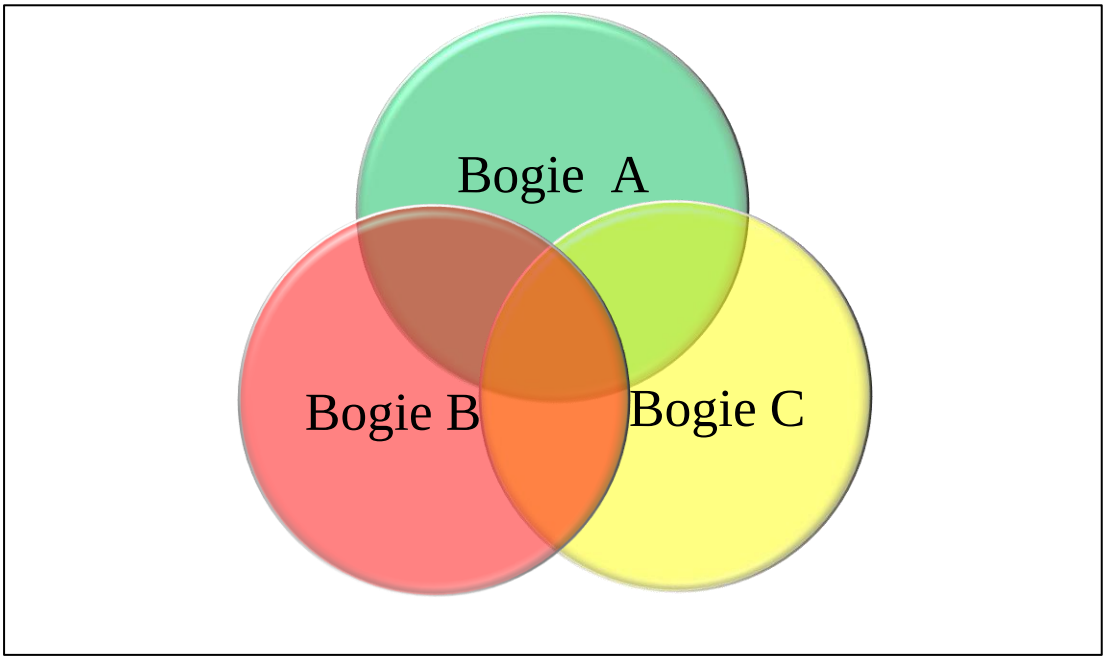


Figure 2 Analysis scope of bogie technology

The development path analysis based on patent citation network has always been a hot spot in history. The main research contents include the development trend of technology, the frontier comparison of technological development, the main path identification of technological development, the characterization and development network of technical evolution. The main categorized research methods are patented citation analysis, text mining analysis, technology life cycle model, TRIZ theory and network analysis. Huang[2] used solar cells to analyze the dynamic path of patent technology by observing the technical development stage and using patent citation networks to identify the technical dynamic path changes. This method is more accurate compared with the static technical path research. Zhang[3] pointed out that the patent citation information had been applied to the evolution of technology because of its characteristics such as technical inheritance, easy acquisition, easy qualitative and quantitative research. Identifying the main path of technology evolution by identifying the "key path" of the patent citation network is one of the focuses of technological evolution. Hummon[4] introduced path search algorithm such as search path link count (SPLC) and the search path node pair (SPNP), so as to find a way to dig out key path of citation network. Verspagen[5] applied this method to the technical path identification in the field of fuel cell, confirming the feasibility of two path recognition algorithms in the patent citation network. Verspagen also proposed a new algorithm NETP (network of the evolution of top path), revealing the optimal path after changes of a certain time interval occurred. Choi[6] proposed a forward citation node pair (FCNP). These are analyses history of technology development path from the perspective of citation.

The technology life cycle (also known as the technology adoption lifecycle) is a sociological model that is an extension of an earlier model called the diffusion process, which was originally published in 1957 by Joe M. Bohlen[7]. There are five kinds of methods to judge the technical life cycle by the characteristics of patent information, which are, respectively, S curve method, patent indicator method, relative growth rate method, technical life cycle diagram method and TCT method. Verhulst[8] proposed the S-curve theory in 1983, which points out that the emergence and development of a technology has its own trajectory to follow. Its occurrence is like the human life cycle, and its shape is similar to the S shape. S curve mainly includes two kinds: one is symmetrical S-curve, also called Logistic curve; another is asymmetric S-curve, which is named Gompertz curve. In the scope of application, the Logistic curve is more common[9]. The patent indicator method calculates the patented product lifecycle by calculating the values of technology growth rate (v), technical maturity coefficient (α), technical aging coefficient (β) and new technical characteristic coefficient (N)[10]. The relative growth rate method uses the relative growth rate of a certain technical field and the relative growth potential rate of the two-dimensional matrix analysis technology[11]. The technology life cycle method is drawn from the use of patent applications and changes in patent filers over time[12]. TCT algorithm is expressed in terms of the number of intermediate ages of all citations in the title page of its application[13].

The technology regional diffusion phenomenon is reflected in the flow of technology products, services and intellectual property rights. The scope and speed of technology geographical diffusion is a more objective response to the impact and importance of technology. The patent office distribution and the patentee's nationality are intuitively display of technical regional diffusion.

Some studies have suggested how to construct patent technological development in the forms of network and positioning maps, which are largely grouped into citation-based and content-based approaches.[14] As for citation based approach, customary approaches for the development of patent

citation chain rely on experts creating manually. However, the rapid increase in the number of global patents has made it difficult to construct patent citation chains in this manner[15]. We use google patent for patent citation data collection. Google Patent search is a search engine of google. In which major patent data records are included. The service was launched on December 14, 2006 and updated in the following years till 2012 with coverage of the European Patent Office (EPO) and the Prior Art Finder tool. In 2013, it was expanded to cover World Intellectual Property Organization (WIPO), German Patent and Trade Mark Office (DPMA), Canadian Intellectual Property Office (CIPO), and China's State Intellectual Property Office (SIPO). All foreign patents were also translated into English and made retrievable. In 2016, it was expanded to cover Japan Patent Office(JPO) and Korean Intellectual Property Office(KIPO) and so on. For these facts, few researchers use google patent as their patent search tool before.

Conceptual and methodological research is the main direction of predicting patent technology development. Patent integrity citation analysis of technology development is not plentiful because the original patent database for citation information is insufficient. This article is based on the newly launched and improved Google Patent search system, which is more accurate in ferreting out the complete chain of patent citation, and drawing patent citation network tree. This paper analyzes the patent development of bogie technology from two aspects: generational patent citation tree and patent count. For the first time, the technical on-orbit rate is used to analyze technology development path as well as the generated patent life cycle method to analyze the technology life cycle, which are research innovations beyond frontiers' work.

The research structure of this paper can be divided into four parts. The first step is patent data acquisition, we use the Google Patent database to retrieve the required bogie patent; the second step is data processing, we use data processing and visualization software including VANTAGE POINT, EXCEL, GEPHI, E-CHART, MAP-DRAWING to conduct this work. The third step is the technical development analysis, including the technology development path analysis, technical life cycle analysis and technical regional diffusion analysis, and corresponding conclusions are put forward afterwards; the fourth step harnesses random sampling method to verify the conclusions. The research framework is shown in Figure 3.

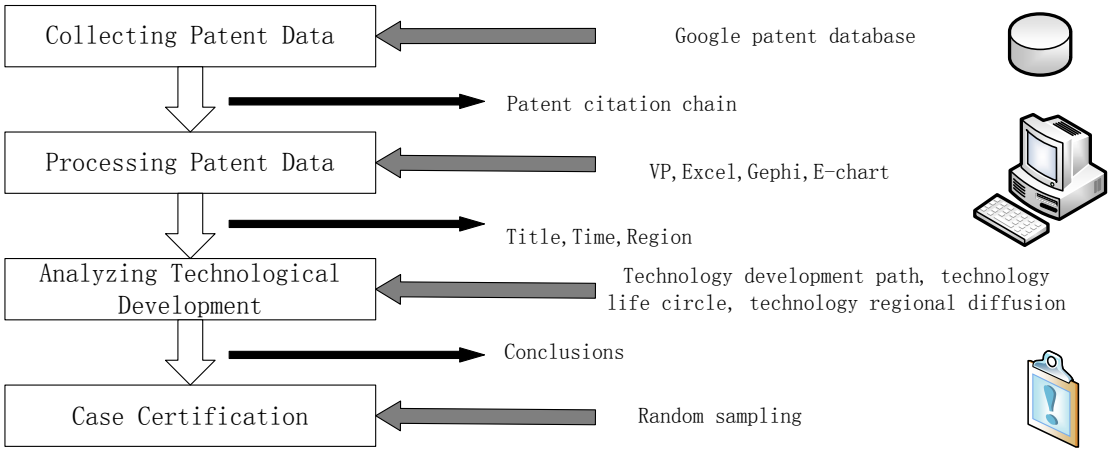


Figure 3 Research framework

Data

Data acquisition

(1901/12/31, US690330A, 4, bogie), patent of the first generation is titled bogie, bogie is the technical object of this patent. As a starting point, we expand the citation chain, then downloading all directly cited patents of it, defined as second generation patent. After that, we download all directly cited patents for each second-generation patents, defined as the third generation of patents, etc. Eventually, we download all the existing cited patents. The citation between patents has a strict chronological order, that is, the cited patent is always before the patent, hence the absolute size of the citation network is limited for a period of time.

The second generation of the chain has four cited patents. The technical object of second generation are movable side frames, releasing stabilizer, side bearing and yaw control, respectively. The second generation of patent is characterized by a large part of bogie. The third generation has a total of 60 directly cited patents. With the patent generation extension, the bogie technology development gradually refined in depth and technical components began to refine. Among the 60 third generation patents, 37 patents have no cited patents. For the fourth generation patents, a total of 274 patent records were found, of which 169 patents have no cited patents. For the fifth generation patents, a total of 1099 patent records were found, of which 642 patents have no cited patents. The fifth generation patents have expanded their technology from bogie physical components to some other fields, like the concept of model, integrated circuit layout design, modern communication technology and electronic technology. With the extended generations, we ultimately find one longest citation chain, which has 13 generations. As the amount of data is too large in the overall analysis, only limited to the fifth generation.

Data processing

We search bogie technology patent data with at least five generation patents, and draw the patent citation network tree. Because some patents will also quote intergenerational patents, for example, the fourth generation of patents also cited the second and third generation of patents, in order to avoid duplication in the patent network tree patent, we will define the earliest advent of this patent as its generation. Based on this principle, the first generation has one patent, the second has four patents, the third has 60 patents, the fourth has 139 patents and the fifth has 1099 patents. The patent citation network tree is shown in Figure 1. The size of the dot is drawn according to the proportion of cited patents. Because there are also citations between the same generation, rendering the figure some connections between the same generation. On the whole, the figure shows that the number of patent citations is expanding.

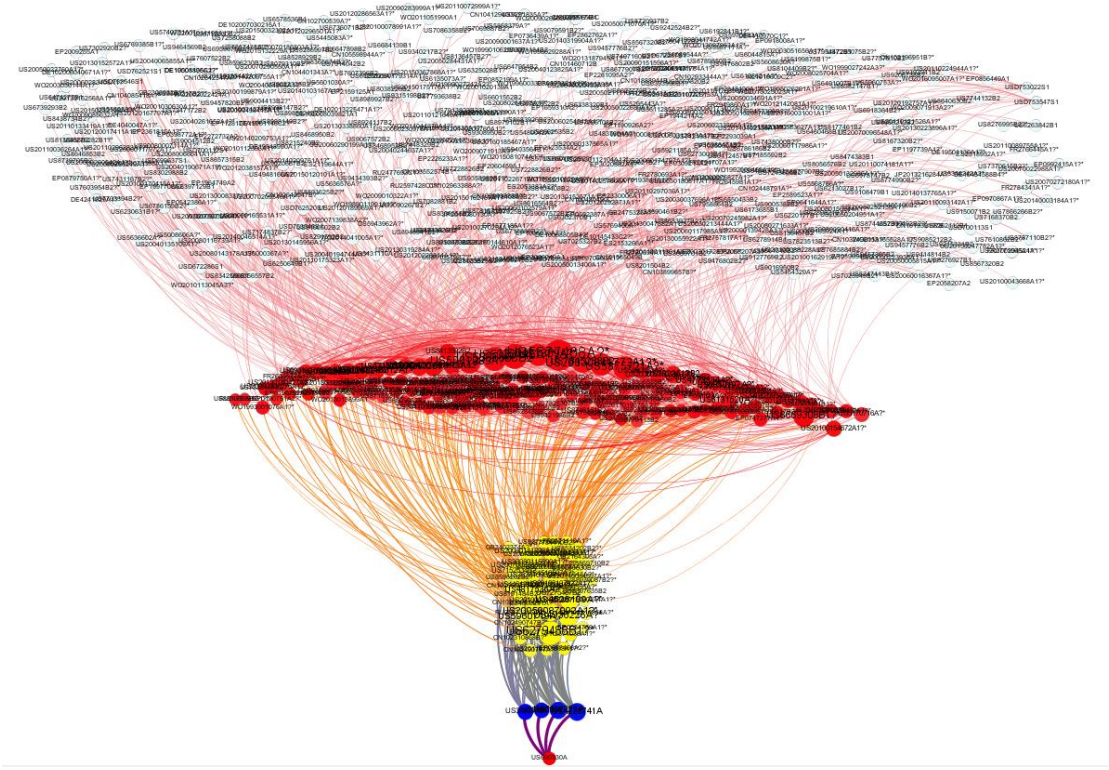


Figure 4 Patent citation tree with five generations

The analysis of bogie technology development

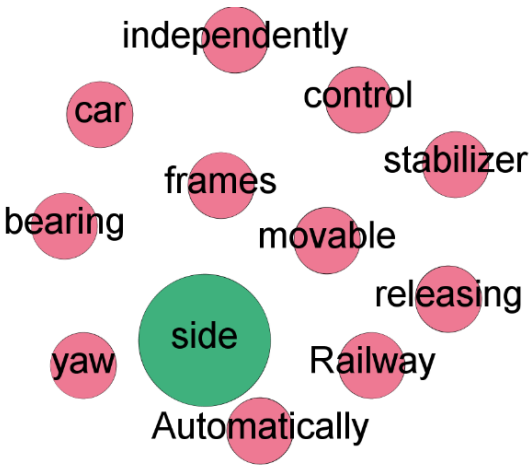
The analysis of technology development path

The analysis of patent title keywords

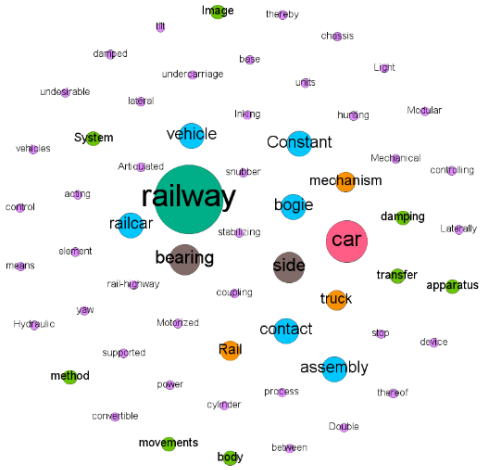
The title of patent is the most general technology summary for a patent, whose information is beyond patent citation information. We determine whether the patent technology is directly related to the bogie technology through the method of expert judgment. In this paper, two-step method is used to determine the patent title keywords.

1. Find relevant patents and identify the main keywords involved in the bogie technology;
2. Through the word frequency of patent literature, mining the main bogie technology keywords.

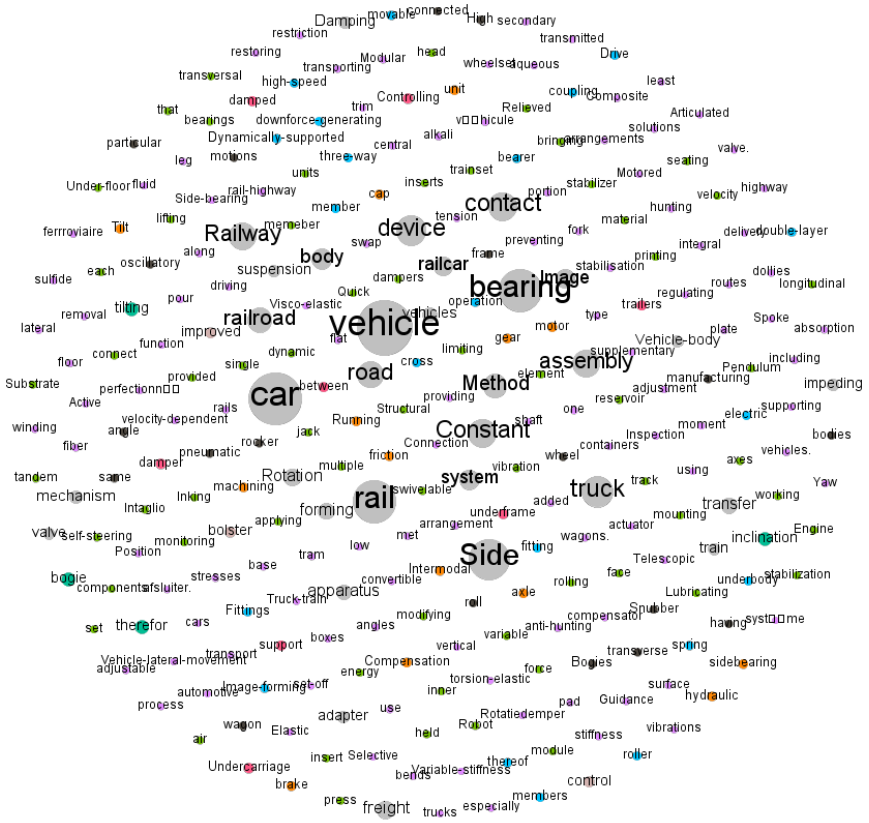
The graph for generational patent title keywords is shown in Figure 5.



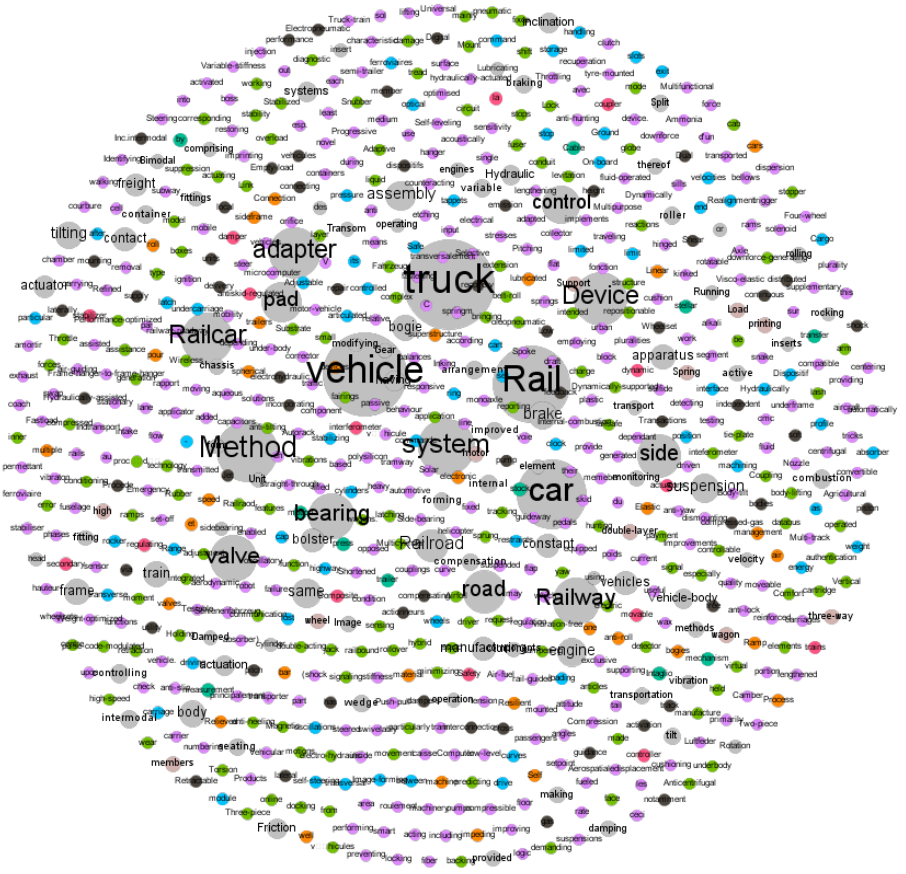
A. The second generation



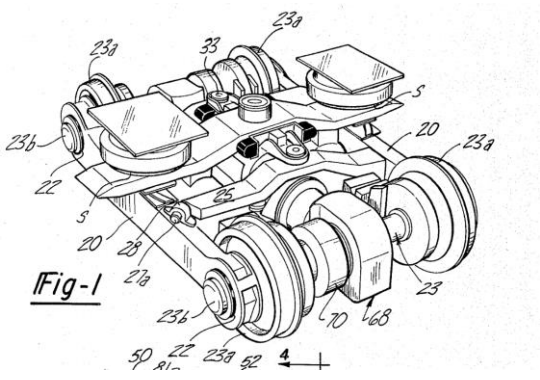
B. The third generation



C. The fourth generation



A. Decentralized power bogie [16]



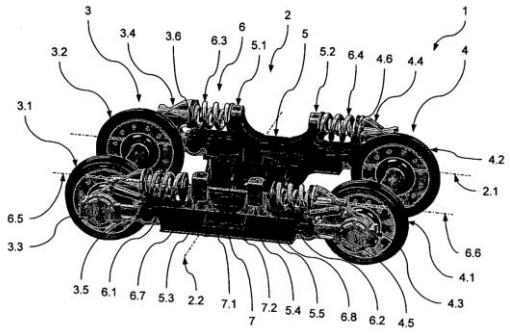
B. Centralized power bogie [16]

D. The fifth generation

Figure 5 Generational title keywords of patent

As can be seen from Figure 5, the number of keywords increases with the generational increase, which has one in the first generation, 12 in the second, 60 in the third, 276 in the fourth and 721 in the fifth. Overall, the descendants of technologies are more divergent than previous one.

The construction of technical classification



C. Trailer bogie [17]

Figure 6 The main types of technology diagram of bogie

Combined with the patent literature and the existing professional technical classification and based on the main types of bogie, we establish the bogie technology classification. Details are shown in Table 1.

Table 1 Bogie technology classification

bogie	bogie frame	side beams	
		beams	
		longitudinal beams	
		air spring beam	
		brake beam	
	axle box with roller	wheel frame	wheel
			wheel axle
			brake wheel disc
			brake axle disc
		axle apparatus	axle box tumbler
			axle box hoop
			axle box gland
			axle box bearing
	primary suspension	elastic locating node	
		coil springs apparatus	spring
			spring control arm
			rubber elements
		axle box vertical damper	
	secondary suspension	air spring apparatus	air spring capsule
			emergency rubber heap
			cover
		traction device	traction pin
			traction rod
		damper	lateral damper
			anti-yaw damper
			vertical damper

		anti-roll bar	torsion arm
			torsion axle
			lever
	brake system	brake lining	
		brake clamp	
	driving device	gearbox	oil level checking device
			bearing
			temperature sensor device
			fusing relay
		traction motor	traction motor
			electric shock absorber
			motor elastic block device
	auxiliary device	stone sweeper	
		velocity sensor	
		grounding device	
		lubricating device	

Data source：collected by authors

From the technical classification, 71 bogie technology key words can be found in Table 2.

Table 2 Bogie technology key words

absorber	block	disc	hoop	relay	sweeper
air	bogie	driving	lateral	rod	system
anti-roll	box	elastic	level	roller	temperature
anti-yaw	brake	electric	lever	rubber	torsion
apparatus	capsule	elements	lining	secondary	traction
arm	checking	emergency	locating	sensor	tumbler
auxiliary	clamp	frame	longitudinal	shock	lubricating
axle	coil	fusing	motor	side	velocity
bar	control	gearbox	node	spring	vertical
beam	cover	gland	oil	springs	wheel
beams	damper	grounding	pin	stone	with
bearing	device	heap	primary	suspension	

At the same time, we add 25 highly related words from expert judgement. Details are shown in Table 3.

Table 3 Added bogie technology key words

actuator	body	engine	mechanism	stabilizer	valve
adapter	bolster	Inking	module	transfer	vehicle
articulated	car	inter	monitor	truck	vibration
assemble	constant	machine	railway	unit	yaw
automotive					

The all 96 keywords are used to analyze the development path of bogie technology.

The analysis of technical on-orbit rate

Technical on-orbit rate is defined as the domain keywords appear frequency rate. The algorithm

in detail: $P_i = F_{Ai} \times A / (F_{Ai} \times A + F_{Bi} \times B) \times 100\%$.

A is a keyword of the 96 keywords, B is a keyword beyond of the 96 ones. F_{Ai} stands for the frequency A appeared in generation i, F_{Bi} the frequency B appeared in generation i. The calculation results are:

$P_1 = 1/1 \times 100\% = 100\%;$
$P_2 = 10/13 \times 100\% = 76.92\%;$
$P_3 = 83/117 \times 100\% = 70.94\%;$
$P_4 = 920/1480 \times 100\% = 62.16\%;$
$P_5 = 3212/5489 \times 100\% = 58.51\%.$

The technical on-orbit rate change trend is shown in Figure 7.

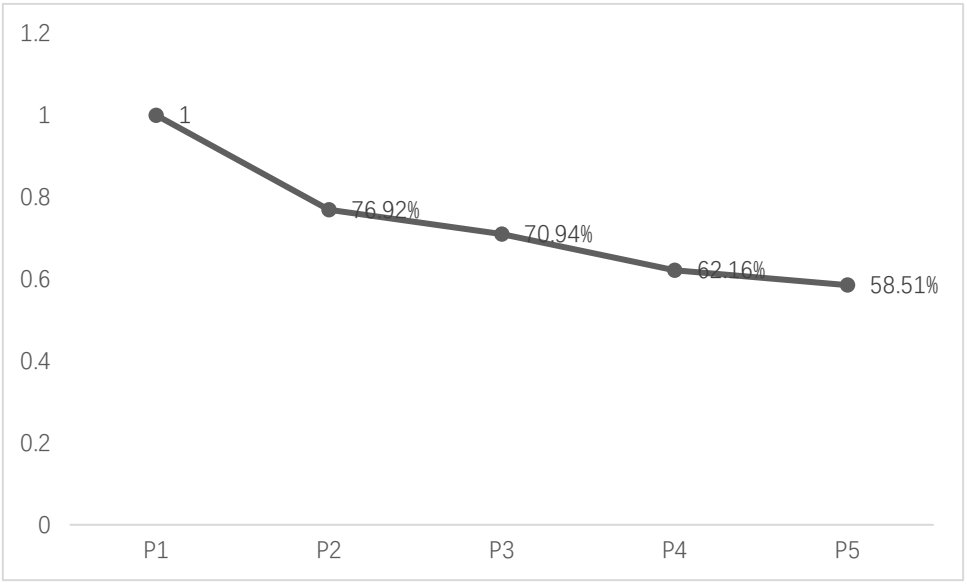


Figure 7 The technical on-orbit rate of Bogie technology

As can be seen from Figure 7, the convergence of technological development is getting smaller, that is, technology continues to spread, but the rate of decline is slow. The rate is still close to 60% until the fifth generation. It is clear that the development of bogie technology is relatively high in the main path.

The analysis of technology life circle

Because the patent data of this paper is classified according to generations, so there are partially overlapping patent data, and because there are inter-generational citations and adjacent generations citations, some patents appear more than once in different generations. The analysis method of technology life cycle is different from the traditional one. We use the method in Figure 8 to analyze the technology life circle.

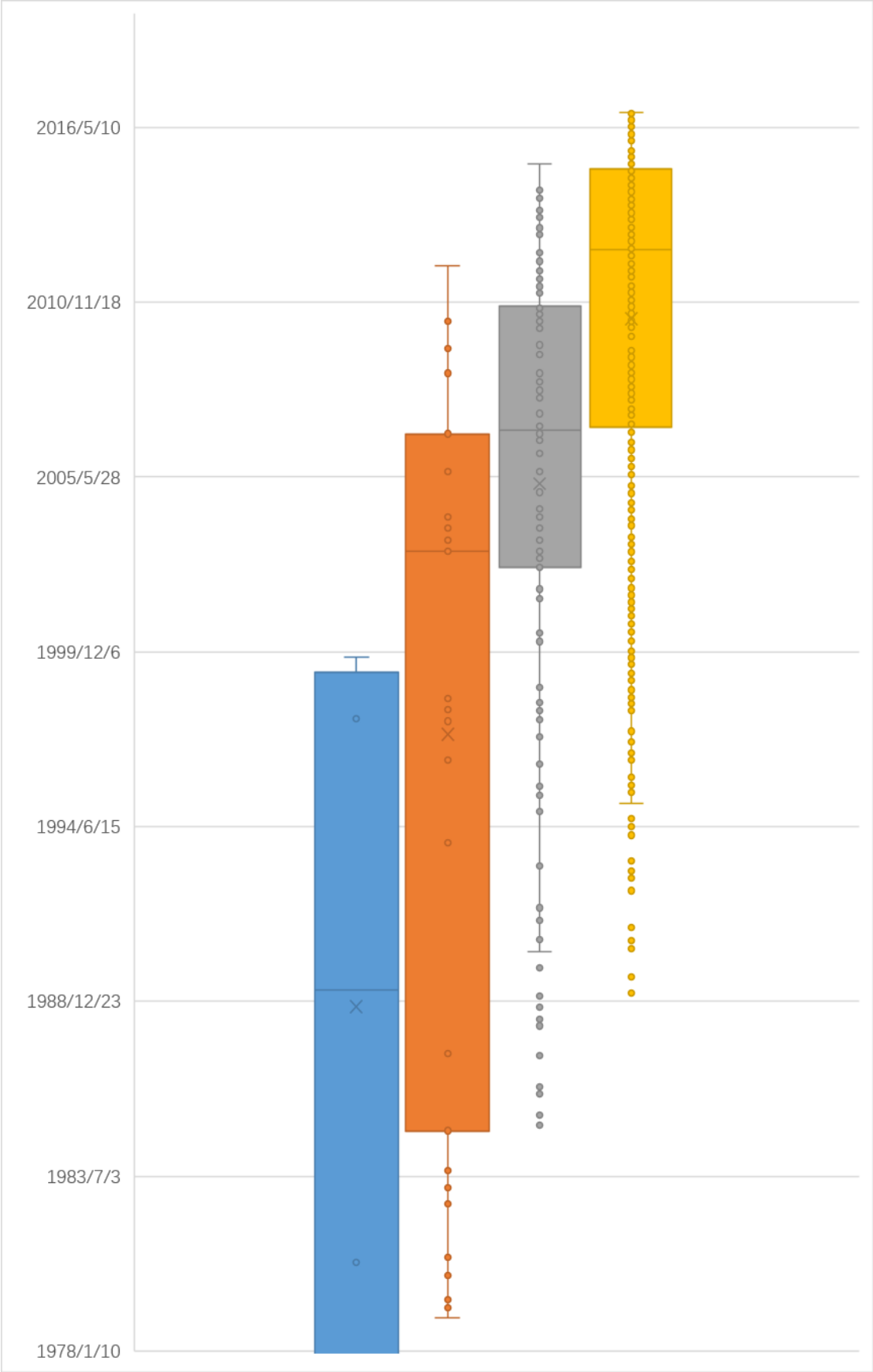


Figure 8 Technology life circle analysis according to generational classification

Notes: In the figure, the "X" symbol indicates the average public time position of patents, the spots outside the short line are outliers, the shaded part is the quartile position, and the inner long line is the middle dividing line.

The average public time of the four generations patent are 1989, 1998, 2005 and 2009 respectively. Most of which were concentrated between 1978 and 2016. The intergenerational median reflects the main agglomeration time section. It can be seen from Figure 8 that the main gathering interval is decreasing, the burst period of technological breakthrough is concentrated and the rate of technical information flow is accelerating. Moreover, over time the distance of the patent is shrinking, and the speed of technology replacement is accelerating. Thus, until March 2017, from the viewpoint of technology life cycle, the bogie technology breakthrough is still on the rise.

The analysis of technology regional diffusion

The patent citation flow contains information about the regional mobility and market diffusion. The first three generations of patents are basically US patents, the fourth and fifth ones began to diffuse. Our technical cross-regional flows here are based on patent applications. The global flow of bogie technology in the fifth generation is shown in Figure 9.

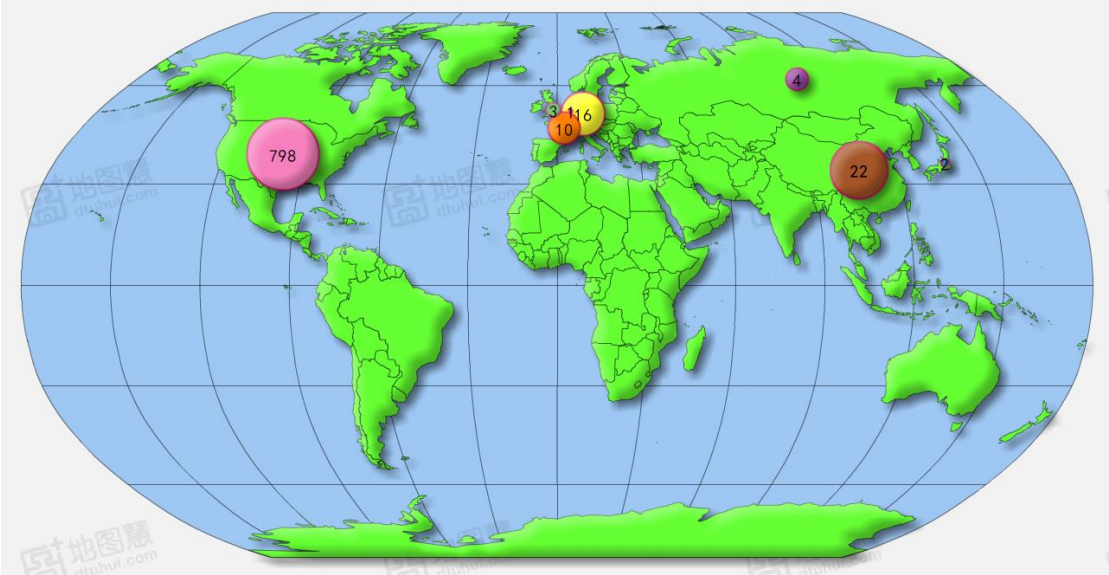


Figure 9 The global flow of the fifth generation bogie technology

It can be seen from Figure 9 that the main technology is concentrated in the United States, Europe and China. But as we know, the comprehensiveness of patent citation data in different patent offices are different, the United States has more comprehensive data, while other patent offices are lagging in this aspect. Overall, the spread of technology is mainly in China, Germany, Japan and several other technology power of high speed rail.

Conclusions

We argue that the development of bogie technology demonstrates the following characteristics: 1. Patent citations expand with generation developing, bogie technology life cycle is still in the growth period. 2. Technology development path is clear and patent on-orbit rate is high, which means the citation patents are still highly related with bogie technology. 3. Bogie technology develops globally at a slow speed and on a small scale. 4. The intergenerational average time is shorter over time, which means technology breakthrough is accelerating.

Case certification

We find a typical patent citation chain to verify the conclusions. As is shown in Table 4.

Table 4 Sample patent citation chain

Publication number	Priority date	Publication date	Assignee	Title
US690330A *	1901/9/21	1901/12/31	Illius Augustus Timmis	Bogie for railway rolling-stock.
US4228741A *	1977/12/22	1980/10/21	Paxton & Vierling Steel Co.	Automatically releasing stabilizer
US4936226A *	1979/5/21	1990/6/26	A.Stucki Company	Railway truck snubber
US5577468A *	1991/11/29	1996/11/26	Caterpillar Inc.	Engine valve seating velocity hydraulic snubber
US5713316A *	1995/5/17	1998/2/3	Sturman; Oded E.	Hydraulic actuator for an internal combustion engine
US6557506B2 *	1994/4/5	2003/5/6	Sturman Industries	Inc.
US20020157650A1 *	2000/2/16	2002/10/31	Herman Gaessler	Method and circuit system for operating a solenoid valve
US7044092B2	2003/6/23	2006/5/16	Magneti Marelli Powertrain S.P.A.	Method and device for controlling an electrohydraulic unit for actuating the valves of an endothermic engine
US20060196455A1 *	2005/3/1	2006/9/7	Jones James W	Linear fluid engine
US7258086B2 *	2005/2/24	2007/8/21	John William Fitzgerald	Four-cylinder
US20090308073A1 *	2006/7/26	2009/12/17	Dante Patrick Bonaquist	Oxygen enhanced combustion in industrial processes
US20140202206A1 *	2013/1/22	2014/7/24	Steen Research	Llc
WO2016149291A1 *	2015/3/17	2016/9/22	Steel Research	Llc

1. Patent citations expand with generational growing, bogie technology life cycle remains at the growth period. This conclusion applies in limited generations, as far as five generations in this paper(seen in Figure 4), this conclusion is correct. 2. Technology development path is clear and patent on-orbit rate is high, which means the citation patents are still highly related with bogie technology. From the patent title, the bogie technology developed to the bogie stabilizer, and gradually to the engine temperature control. In the eighth generation, the technology is still on the main path. Although patents began to extend to other fields after eighth generations, but taking eighth generations on-orbit into account, it has already a very good performance. 3. Developing across the global with a slow speed and on a small scale. We can see that only the 13^{th} generation is

a patent registered in WIPO, the others are all US ones, which seems certified the low diffusion speed of bogie technology. 4. The intergenerational average time is shorter over time, patent applications have become more frequent and this phenomenon illustrates technology updates faster.

Limitation

The research process and the research methods of this paper remain to be improved. For example, we use patent application office to analyze the regional diffusion, but some citation information is missed in many national patent offices except for the US. The use and improvement of new methods has not been systematically justified, and the effects need to be tested, such as the use of technical on-orbit rate and the use of generational patent life cycle, which are all points to be improved in the future.

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