Technology Early Warning Model: a New Approach Based on Patent Data

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ABSTRACT
With the development of technology, more and more technical issues have been exposed, such as technical disputes, technical barriers and technical crisis. Thus, it is necessary to warn enterprises about technical deviation and predict future technology crises. Patent data can contain much information about technologies and would be useful in this setting. This paper proposes a technology early warning model based on patent data. This model helps enterprises analyse the technical crisis level and trends from four different perspectives (technical stability, technical monopoly, technical security and technical prospects).

Keywords
Technology early warning, Patent data, Technical crisis, Indicators

1. INTRODUCTION
With the development of science and technology, many enterprises, especially high and new technology enterprises, started to focus on research and development of technology. However, as a result of the development of economic globalization, there are many technology disputes between enterprises all over the world every year. Thus, it is necessary for enterprises to take some measures to avoid these dispute and keep their technology advantage in a fiercely competitive market. We address this in our paper and we aim to provide an effective method for enterprises in technology early warning.

The phrase early warning derives from military planning, refering to predicting enemy attacks, giving the alarm in a timely manner and preparing the appropriate response to avoid significant loss (Jiezhu Pan, 2007) [1]. In other fields, early warning is a forecast method for crisies which could threaten that field's normal operation, and offer directions for preparation (Congmin She.2003) [2]. This can offer enough time for early warning subjects to take mearsures before crises happen. It also can help early warning subjects to reduce significant loss as a result.

The concept of technology early warning was first put forward by the U.S. military. In this concept, technology early warning refers to the alertness to a "technical raid" which potential rivals may form in advance to keep military advantage in technology (Boao Qin.2006) [3]. Yang Cai (1989) [4] redefined it, pointing out that technology early warning is a process from technology forecast and relevant factors' breakthrough to give the alarm to decision makers. Yujie Zhang (1999) [5] defined technology early warning in enterprise as a security alarm of technical deviation and technical catch up situations which remind enterprises take measures to keep a technical advantage. In this paper, technology early warning is regarded as forecast and alert for technical crisis which would threaten enterprises' sustainable development, and lose their technological advantage.

In order to execute technology early warning, technology information needs to be considered. Many enterprises apply for patents to protect their technology infringment by other actors, and are effective means to protect intellectual property. Recent studies have used patent information to study technological developments, trends and potential (Zhang, 2011; Pilkington et al., 2009) [6-7] as well as decision making in research and development (Thorleuchter et al., 2010) [8]. Information from patent data allows companies to avoid investing in obsolete technology (Wang et al., 2012) [9] and it enhances strategic planning (Abraham and Moitra, 2001) [10]. Patent analysis also offers key information concerning the technology environment (Porter and Cunningham, 2005) [11] and addresses component technologies (Trappey et al., 2012) [12]. Patent data is suitable to analyze technology in enterprises and this paper will develop patent analysis further by introducing perspectives on technology early warning.

Currently, there are few studies which incorporate technology early warning with respect to technical crisis and combine this with patent data. Therefore, we propose a new method for the technology early warning model based on patent data considering forecasting of technical crisis. We aim to contribute to improve technology early warning systems. This paper identifies, analyzes, and indicates the technology crisis, and then establishes the technology early warning indicators and a model based on

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patent data. We aim to provide a new method for enterprises to solve problems in technical disputes, technical deviation and technical catch up situations before they happen.

This paper is organized as follows. The literatures about technology early warning are reviewed in Section 2. Model of technology early warning based on patent data are proposed in Section 3. Conclusions and future research directions are provided in Section 4.

2. LITERATURE REVIEW

To establish a better technology early warning model, we experimented with information on technology early warning research status from a broad perspective in a bibliometric database. This gave us a perspective on the theoretical concepts and current trends in the literature of early warning. Our results show a wide range of information about the current research fields, previous methods and current critical dialogues of technology early warning research.

Firstly, we searched in “Web of Science” using a boolean search term-“Topic= (technology early-warning OR technology early warn OR tech early-warning OR technology early warning OR technical warning)” to study the current research trends and indicate the leading field of technology early warning researchs. We generated 3436 results which indicated a sufficent quantity of research to be worth analysing in a bibliometric database. After that we downloaded these documents and processed them using VantagePoint (a software for data processing), locating 135 items related to management sciences. We can observe that while there have been many studies ontechnology early warning, there have been fewer in management sciences and is worth considering in the context of enterprise readiness for technical crisis. .

We extracted keywords in 3436 papers and selected the top 200 which were clustered in a visualisation- see Figure 1. From Figure 1 we can see that keywords in previous technology early warning research has mainly clustered into four categories which are “health care”, “computer technology”, “management” and “perception”. However, as we can see in Figure 1, “GPRS” and “early warning score” are the main research domains within management science. However, this paper will address different perspectives in “technology early warning” and combine this with technical crisis values. To learn more about research in management science, we ranked papers’ keywords which appear more than twice – see Table 1. From Table 1 we observe that much research focuses on early warning methods or systems. These studies utilize computer technology (such as data mining and AHP) to simulate or forecast alert situations. From these keywords, we also build on the quantifiable methods used by many of these papers in our research.

In tandem with publication data considering technology early warning models, we addressed the development of technology early warning in a patent database. Initially, we searched in “Web of Science” with a boolean search term- “Topic= (patent) AND Topic= (technology early-warning OR technology early warn OR tech early-warning OR technology early warning OR technical warning)” and generated 8 results, with none related to management science. We altered the ‘topic’ term to “patent AND early warning” and generated 17 results, with 5 papers explicitly mentioning patent data in early warning but no reference was made to technology early warning. Of the total, four papers where relevant for our study.One study, commented on the research literature of early warning mechanisms in China, and presented an international case study of a successful early warning technique using patents (Jianping G, 2011)[13]. Another paper discussed the importance of establishing patent early warning systems to forecast potential patent risks and analyzed the main reason of patent risk. It proposed three basic functions of a patent risk early warning system. This paper also presented a basic framework and model of that system (Han, Hongqi; Wang, Xuefeng, 2008) [14]. Another paper proposed patent infringement litigation early warning indicators and a model for pharmaceutical enterprises.

Table 1. Keywords in management rank

Times	keywords
18	Early warning system
17	Early warning
10	Technology
7	Technology Innovation
6	Risk management
5	Classification; Crisis; Data mining; Discriminant-analysis; Management; Model
4	China energy; Complex adaptive system; Construction project; Consumption; Early warning management; Emergency; Indicator system; Information; Real estate; systems; The ability of independent innovation; Trends; Warning system
3	Admissions; AHP; Fuzzy comprehensive evaluation; Governance; Information extraction; Intensive-care; Intrusion detection; Lessons; Logit; Network; Antecedents; Competition; Data and information quality; Deaths; Design science; Early warning score; Environment early-warning; Failure; Financial crisis; Neural networks; Project management; Risk assessment; Sensor-based electronic modified early warning scorecard; Socio-technical information systems design methodology; Stakeholders; Strategy; The model of early-warning

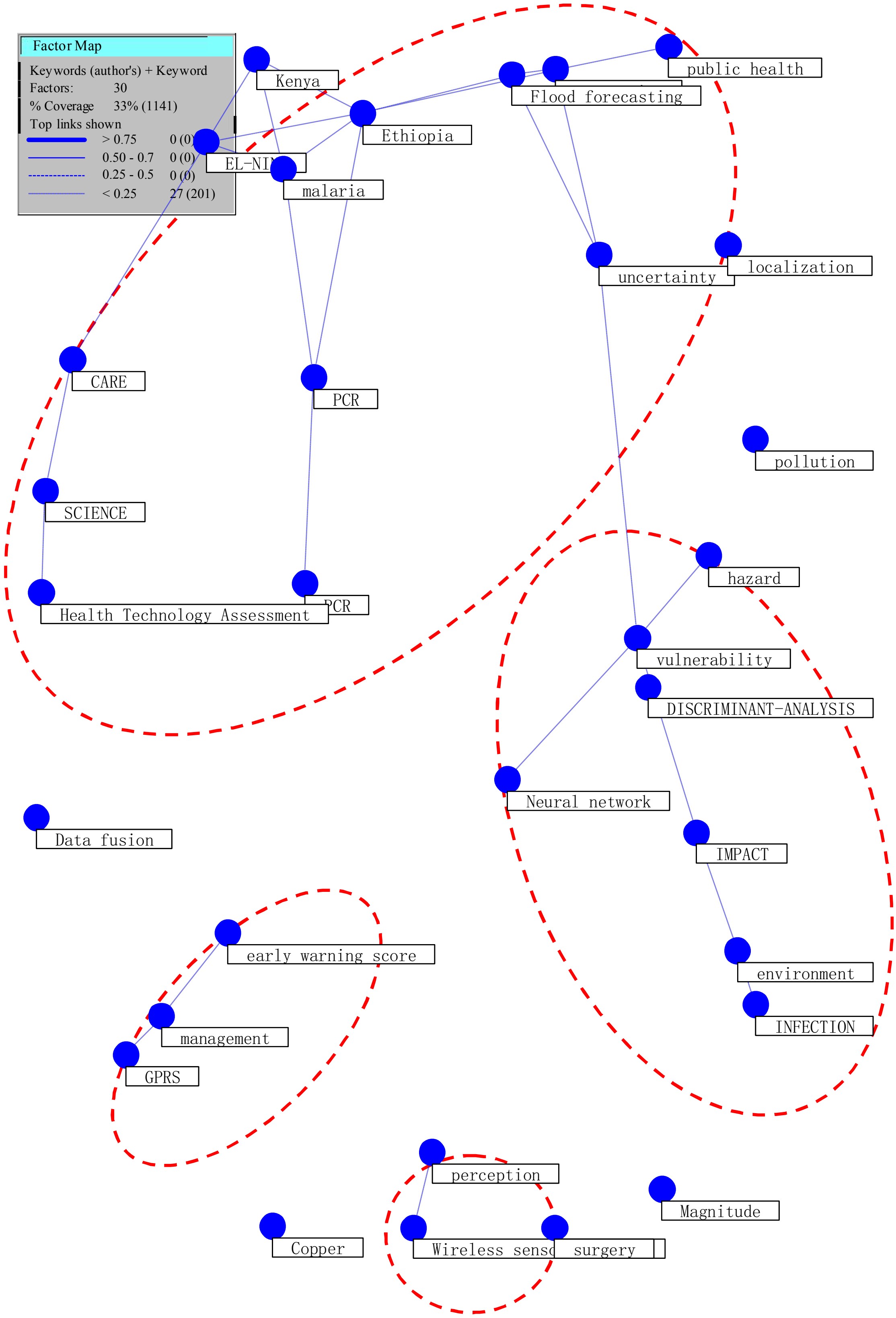

Figure 1. Top 200 keywords' cluster

This also presented a three stage early warning indicator system (Wang, Ying, 2013) [15]. The final paper considers how the patent early warning mechanism can improve innovation abilities of wind power enterprises. They imply that by establishing patent early warning mechanisms, common issues experienced by enterprises in the sector can be resolved through these methods (Peng Yuanyuan, 2012)[16]. These articles imply that while there is growing dialogue on the subject, research on technology early warning combined with patent data is an underdeveloped area worthy of further study.

3. METHODOLOGY

3.1 Research Framework

In this paper, we regard technology early warning as an alert for technical crisis. Technical crisis is a risk that caused by the accumulation of negative factors of technologies', and it will destroy the quality of a technology if unaddressed. Technology has features of stability, monopoly, security, reliability and development potential. However, when technologies are destroyed, it will turn into a technical crisis for the enterprise causing uncertainty, relativity, destructiveness, imperceptibility and gradualness (Lixin Xia et al., 2009[17]; Runhua Tan, 2002 [18]). To forecast technical crisis, we should consider the characteristics. (1)Uncertainty of technical crisisimplies the risks involved in a period of development. Characteristics of the technology, internal and external influences, and limitation of human knowledge could increase uncertainty in these terms. (2)Relativity of technical crisis is caused by different organizational conditions. The same technology may have diffierent risks in different organizations as well as in the same organization, at a different stage of development. Thus, technology crisis may be both an opportunity and a challenge for an enterprise. (3)Destructiveness of technical crisis implies that once a crisis begins, it can cause serious disruption for an enterprise. (4)Imperceptibility of technical crisis implies an event which cannot be detected and may have significant affect on the enterprise. This will contribute to the destructive nature of technical crisis. (5)Gradualness of technical crisis implies the accumulative quality of negative factors in the technology and technical environment. This conceptual outline is demonstrated in Figure 2.

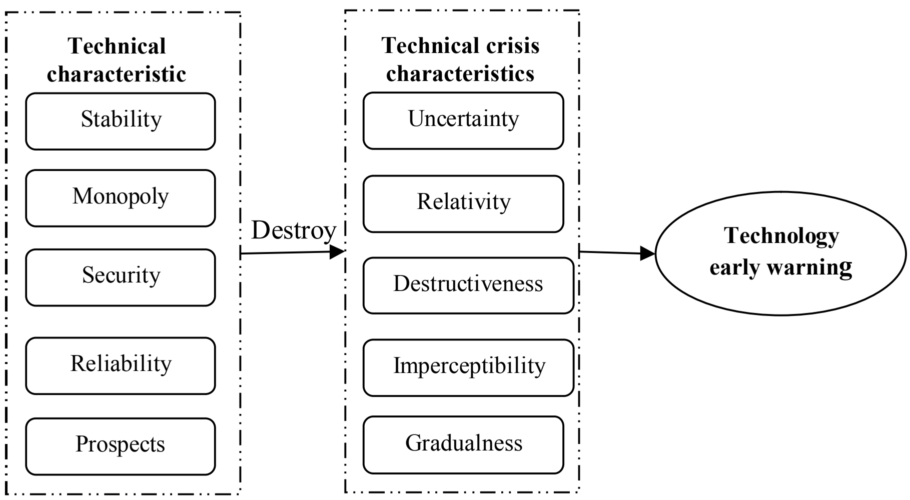

Figure 2.Triggers of technical crisis

With a well defined characteristic model of technical crisis, we can further develop our analysis towards a technology early warning model. Judging technical crisis through enterprises' data directly is a complicated process, so we reflect on thus by using information gained from the technologies. Therefore, this paper will execute technology early warning research through the patent data which displays information about enterprises technology development. This paper aims to answer the following research questions with patent data in enterprises:

- How do we judge whether an enterprise technology will be affected by internal and external factors?
- At what level is an enterprise technology in its field?
- Can enterprises protect their technologies?
- How will enterprises' technology develop in the future?

3.2 Indicators

In order to answer these questions and help enterprise forecast its technical crisis with quantitive methods, we propose four different perspectives (technical stability, technical monopoly, technical secuity and technical prospects) indicators to analyze enterprise technology status. From this we will judge whether an enterprise will encounter technical crisis. From this we can present an 'early warning' index for companies. Based on the rich literature review and consultation with experts, we defined ten indicators to measure these different perspectives. Indicators are shown in Table 2.

Table 2. Indicators and its detailed contents

Perspectives	Indicators	Operational definition
Technical stability	Technology maturity	Enterprise technology's development stage
	R&D staff flow	Change of enterprise R&D staff
	Technical dependence	The degree of enterprise technology dependent on external factors
Technical monopoly	Technical breadth	Research scope of enterprise technology (technical breadth)
	Technical strength	Enterprise technology's strength in research (technical depth)
Technical security	Technical disparity	Differences of enterprise technology
	Technical complexity	Complexity of enterprise technology system
	Technical maintenance	Ability to maintain technology
Technical prospects	Technical progress	Development trend of enterprise technology
	Technical environment	Development trend of the technical field

First, the perspective of technical stability is used to judge if enterprise technology can develop stability and to what extent it will be affected by internal and external factors. This insight is gained from technology maturity, technical staff flow and technical dependence. Technology maturity reflects technical stability mainly through technology life cycle. R&D staff flow reflects technical stability through the number of R&D workers (can be called 'technicists') who apply for a patent in an enterprise. We consider the more technicists are engaged in these activites, there is a higher stability coefficient in the enterprise. Technical dependence is a powerful indicator to reflect technical stability. We argue that if enterprises have a significant dependence on another enterprise technology, they are more prone to technical crisis. The computational formula of each indicator is shown in Table 3.

The second perspective--technical monopoly--is used to judge at what level an enterprise technology is in its field. To achieve this, we consider technical breadth and technical strength to measure technical monopoly. We introduce this indicator to measure research scope of enterprise compared with its rivals and we measure technical breadth as the proportion of the enterprise's technology accounted for in its field. Technical strength reflects technical monopoly in the view of an enterprise's strength in research and development of a technology. We argue that the value of technical strength has a positive influence on technical monopoly. In Table 4 we detail the computational formula of these indicators.

Table 3. Computational formula of each indicator in first perspective

Indicators	Formulas	Explaination
Technology maturity	We calculate Technology maturity based on a growing model and divided this into five levels.	We define the value of maturity stage which is the most stable stage as 5, and the stage closer to maturity stage have higher value.
R&D staff flow	$AI = \frac{TI}{TPE} \times 100\%$	AI: average inventors in patent applications. TI: total inventors to apply for patents. TPE: total patents enterprise has.
Technical dependence	$TDE = \frac{TPF - TPE}{TPF} \times 100\%$	TDE: technology dependence. TPF: total effective invention patents in the field. TPE has the same meaning with above.

Table 4. Computational formula of each indicator in second perspective

Indicators	Formulas	Explaination
Technical breadth	$TB = \frac{\mathrm{IPC_q}}{\mathrm{IPC_h}} \times 100\%$	TB: technical breadth. $\mathrm{IPC_q}$: number of IPC in enterprise. $\mathrm{IPC_h}$: the number of IPC in enterprise's industry.
Technical strength	$TS = NAIP \times ALPE$	TS: technical strength. NAIP: the number of active invention patent in an enterprise. ALPE: average length of patent enforcement.

The third perspective--technical security--is used to measure an enterprise's capacity to protect its technology from damage. Technical diversity, technical complexity and technical maintenance are indicators we use to measure technical securiy. Technical diversity refers technology difference between enterprise and the field. And we argue that with a lower technical diversity value an enterprises technology is more secure. Also, a higher value in technical complexity and technical maintenance means a more robust enterprise technology. Table 5 shows detailed computational formula of these indicators.

Table 5. Computational formula of each indicator in third perspective

Indicators	Formulas	Explaination
Technical disparity	$TDI = \sqrt{\sum_{i=1}^{n} (b_i - a_i)^2}$	TDI: Technological diversity. a_i and b_i means the number of active invention patents in an enterprise and its field distribution in IPC categories, i=1,⋯,n.
Technical complexity	$TC = \frac{NAP}{NIPCC} \times 100\%$	TC: technical complexity. NIPCC: the number of main IPC categories. NAP:number of active patents in an enterprise
Technical main-tenance	$AEG = \frac{TNIP}{NAP} \times 100\%$	AEG: average effective age of technology. TNIP: the total number of invention patents in an enterprise.

Finally, the perspective of technical prospects is proposed to estimate the development prospects of an enterprise technology. We introduce technical progress and technical environment to measure this. Technical progress reflects technical prospects from the variation of patent numbers. We argue that technologies will develop well in the future when patent numbers increase rapidly. The technical environment reflects technical prospects of the field and how the enterprise is affected by it. We argue that an enterprise technology will have the same potential of development as the field it inhabits. Computational formula of each indicator is shown in Table 6.

Table 6. Computational formula of each indicator in third perspective

Indicators	Formulas	Explaination
Technical progress	$IAR = \frac{NPC - NPP}{NPP} \times 100\%$	IAR: increase of application rate for invention patents. NPC: number of patents by enterprises in current period. NPP: number of patents of enterprises in prior period.
Technical environment	$IRAP = \frac{NAPC - NAPP}{NAPP} \times 10$	IRLP: the increase rate of active patents. NLPC: number of active patents of industry in current year. NLPP: number of active patents of industry in prior year.

3.3 Process

Based on indicators shown on 3.2, this method will also address the wieghting and degree of alertness which helps in the analysis of technical crisis.

(1) Weighting

AHP (Analytic hierarchical Process) is a powerful decision analysis technique for multi-criteria decision-making, and it can decompose problems into a hierarchy of goals, attributes, criteria and alternatives. Therefore, after the calculation of each indicator with patent data in 3.2, we used AHP to weight each indicator. Table 7 is the result of the weighting of each indicator.

Table 7. Summary list of the indicators

Rule level / Indicators	Technical stability	Technical monopoly	Technical security	Technical propsects	Synthetic weight
	0.0507	**0.1781**	**0.5539**	**0.2172**	
Technology maturityC11	0.6434				0.0326
R&D staff flowC12	0.0738				0.0037
Technology dependence C13	0.2828				0.0143
Technical widthC21		0.1667			0.0297
Technical strengthC22		0.8333			0.1484
Technical diversityC31			0.1530		0.0847
Technical complexityC32			1.0548		0.5843
Technical maintenanceC33			0.4010		0.2221
Technical progressC41				0.8333	0.1810
Technical environmentC42				0.1667	0.0362

(2) Setting alert degree

In this model, we calculate the total evaluation score by multi-objective linear weighting function. Formula of enterprise technical crisis is shown as follows.

$$T = \sum_{i=1}^{m} W_i \sum_{j=1}^{n} \left(R_{ij} W_{ij}\right)\left(i = 1 \sim m; j = 1 \sim n\right)$$

Table 8. Alert Degree and its meaning

Degree of technical crisis	Score	Meaning
Safest (A)	0~1	Technical crisis in enterprise is slight, and it will not affect enterprise's interests and actions.
Safer (B)	1~2	Technical crisis is not serious, and it will only cause minor damage on the enterprise.
Safe (C)	2~3	Enterprise technology has a certain crisis, and it will affect the enterprise's interests and actions but will not be fatal.
Risky (D)	3~4	Technical crisis in an enterprise will bring cause a signifcant loss. The possibility of technical disputes will rise.
Highly Risky (E)	4~5	Technical crisis is inevitable, and it may directly threaten the enterprise's survival.

Wherein T means the degree of enterprise technical crisis, m means the number of perspectives, n means the number of indicators in each perspective. And Wi means the weight of ith perspective.Wij is the weight of jth indicator in ith perspective, Rij is the grade of jth indicator in ith perspective. We outline degree of alertness in Table 8. Enterprises can know their technical crisis level and safety situation by the value of T contrasted with Table 8.

4. CONCLUSIONS

The objective of this study is to propose a new approach of technology early warning with patent data. To this end, we analyzed existing literature in the Web of Science to find the research situation of technology early warning and some studies combined with patent data. Based on the previous studies of technology early warning, we proposed four different perspectives to consider patent and technical crisis characters and defined ten indicators to analyze these perspectives. After that we analysed the weighting of each indicator, and set the degree of alertness to measure the degree of technical crisis theenterprise faced.

This study offers some direction for forcasting enterprise technical crisis using patent data. The model for technology early warning can be used to reduce technical disputes and technical barriers as well as aid further academic research. These models could be adopted by Enterprises with relevant patent data, to analyze technical crisis and better react to it.

As with any experimental model there are limitations which will need to be improved. The most important one is that as the reason of time and difficult in getting patent data for us, we were unable to verify the index system and model by empirical study. So in the future research, we will do an empirical study to prove the feasibility and rationality of this new method and make it better. Because of much knowledge involved in this research, there are some difficulties caused by abstraction of research contents that make our indicators fuzzy. In the future, another work for us is to research the method of indicator quantitative.

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