J Data Sci. Info. Citation Studies., 2023; 2(2):102-109.
https://www.jcitation.org

Research Article

An Evaluation Method for Modelling a Disciplinary Development Stage

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ABSTRACT
In developing science and technology and working out scientific and technological policy and strategy, it is essential for a country's or area's development to elucidate the developing features of disciplines, estimate the scientific and technical effects and predict the future. Furthermore, it is significant in selecting research topics for a particular field of specialisation. A method for modelling a disciplinary development stage and a mathematical model representing it to elucidate a discipline's developing features is suggested. Moreover, the theory of a product and technology life cycle is extended to one of a disciplinary development stage. Modelling a disciplinary development stage evaluation, which we suggest in this article, can help analyse the developing features of a discipline.

Keywords: Discipline, Development Stage, Product Life Cycle, Technology Life Cycle, Published Article, Scientometrics.

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Received: 11-04-2023;
Revised: 06-05-2023;
Accepted: 15-06-2023.

INTRODUCTION

The development of a new product or technology, its application and the socio-economic growth to be attainable from it can never be possible apart from the development of science, because scientific knowledge and its development are the basis of all activities and successes. Thereby, it takes an essential place in scientific and socio-economic development to analyse the structure of disciplinary development, estimate the current stage and grade, and forecast the steps and design of future development.

Disciplines develop independently and mutually with each other, whereby new knowledge is introduced and new fields come into being. This means that disciplinary development is attributed to structural change, each with its developing features. These features give rise to changes in disciplines and the structure of universal scientific research, the output and speed of its development, etc. So, we should say that these developing features can lead to one scientific research. Scientific research successes are achieved through these features, and science, technology, and socio-economics are developed. Therefore, it is very significant in scientific and socio-economic development to estimate and analyse the developing parts of each discipline. It is a disciplinary development stage evaluation that is suggested to do it.

DOI: 10.5530/jcitation.2.2.14

Discipline represents its own feature at every stage. At the emerging stage of a discipline, a new discipline emerges and theoretical research is insignificant. This is just the beginning of disciplinary development. At the growth stage, the scientific research of a discipline is conducted actively and the disciplinary development becomes striking. At the maturity stage, the scientific research objects of a discipline nearly reach the solution stage and scientific theories become mature.

Once the scientific research successes related to it have been accumulated and so its theory has been scientifically proven since a discipline emerged, the discipline is rarely considered to be an object of research in a scientific research field, which means a disciplinary development has some characteristics from the view of the scientific research process. A disciplinary development stage represents these characteristics.

A disciplinary development stage is the period from the emergence of a discipline to the accomplishment of scientific theory and the change in the disciplinary features during that period. Similarly, to the life cycle of a product and technology, a disciplinary development stage consists of periods of emerging, growth and maturity.

In general, the *Product Life Cycle*, or PLC for short, and the *Technology Life Cycle*, or TLC for short, have been introduced and discussed so that enterprises or groups could forecast the output and demands for their product and technology to guarantee sustainable development. A particular disciplinary development stage can be analysed similarly to PLC and TLC.

The transition from the emerging of a technology to its development phase impacts the evolution of the structure of the collaboration network (van der Pol *et al*., 2018). To identify these first phases of the TLC, a method is developed based on the International Patent Classification. Using this method, the authors identify, when a technology transitions from an emerging technology to a stage in which applications of the technology are found. Moreover, they compare the moment at which this transition occurs to the evolution of the collaboration network for the same technology and show that there is a significant change in the structure of the network when this transition occurs.

Patent and publication data is widely used for the analysis of PLC or TLC (Alencar *et al*., 2017; Gao *et al*., 2013; Trappey *et al*., 2013). The life cycle of OR methodology is discussed in (Schniederjans, 1995).

Life-cycle concepts have been applied to forecast and trends in the publication rates of *Operations Research*, or OR for brevity, methodology journal articles have been explored (Schniederjans et al., 2009). The authors seek to show the accuracy of life cycles to forecast a trend for a single OR methodology. This entails a collection of keywords for OR methodologies from over 8000 journal articles. The results show a life cycle can be used to forecast a trend in OR journal article methodology productivity based on the keyword listings.

To estimate the future development of one technology and make decisions whether to invest in it or not, one needs to know the current stage of its TLC (Gao et al., 2013). The dominant approach to TLC analysis uses the S-curve to observe patent applications over time. The authors suggest life cycle calculation modelling based on multiple patent-related indicators.

In our study, a disciplinary development stage is discussed just from the view of an object of scientific research and of scientific research process. It is of important significance in determining the orientation of scientific basic research to explain at which stage of the development a discipline we take as a research object from the view of applications is. To model a disciplinary development stage we use the theory of a PLC and TLC.

Disciplinary development stages

In a discipline, new scientific and technological knowledge is created and used in the aspect of the socio-economic demands and the demands for scientific and technological development. One discipline has its own peculiar scientific and technological ability, conditions and environment of developments, so the features (e.g., change in demand cycle in the aspect of socio-economic development) target helping new scientific knowledge of the aspect to be created and this phase changes with disciplinary development stages.

A disciplinary development stage means the period from the emerging of a new discipline to when there is not any production of research and development. In a discipline, the phase of research and development is represented by research results achieved in a given aspect each time, i.e., the number of research articles contributed.

The number of research articles has peculiar features at every development stage. Each development stage can be distinguished by these features and it becomes possible to model a universal development stage of a discipline.

From a theoretical point of view, a disciplinary development stage is divided into emerging, growth and maturity, at each of which the emergence of a given discipline-related research articles has a certain feature. In practice, a lot of research work related to the theory of the discipline is conducted in a discipline to result in research articles. Just the number of the articles emerged every year shows the phase of research and development of the discipline, which is the basis of a development stage modeling.

Figure 1 shows the theoretical curve of a disciplinary development stage. As shown in Figure 1, the curve of a disciplinary development stage is made up of emerging, growth and maturity and function $f(t)$ doesn't go out of the point M, the maximum number of articles. As time goes by, the function value comes up to zero. Also, the curve of a disciplinary development stage appears different in the increasing rate of the number of articles at each stage and similar to S-curve.

From the point of view of a development stage, consider the features of a function $f(t)$. First, $f(t)$ is defined on the interval $(t_0, +\infty)$ and attains maximum and minimum value over it. Second, $f(t)$ gets its value nearer to zero as t approaches t_0, that is a variable representing the emerging period of articles and in general we can define $t_0 = 0$. Third, $f(t)$ gets its value nearer to zero as t approaches $+\infty$. Fourth, $f(i)$ reaches its maximum value M in t^*. Fifth, $\forall t \in [t_4, +\infty)$, $f(t)=0$. Sixth, $f(t)$ is a monotone increasing function on $(0, t^*]$. That is, $\forall t', t'' \in (0, t^*]$, if $t' < t''$, then $f(t') \leq f(t'')$.

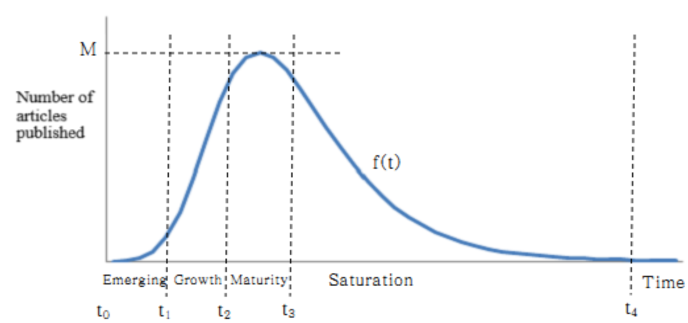

Figure 1: The Theoretical Curve of a Disciplinary Development Stage.

Seventh, $f(t)$ is a monotone decreasing function on $[t^*,+\infty)$. That is, $\forall t', t'' \in [t',+\infty)$, if $t' \le t''$, then $f(t') \ge f(t'')$.

From the analysis of a disciplinary development stage, we can draw the following conclusion. Emerging is the period when a certain discipline emerges and starts to develop; growth when it develops very rapidly; maturity when it develops gradually before it tends to decline considerably. Each disciplinary development stage is different from one another depending on its own feature. This study focuses on a model that can represent disciplinary development stages according to the features.

Modelling a disciplinary development stage

In general, development stage curves are difficult to model because of their theoretical nature. The growth of living things or PLC depends on the S-curve, whereby each stage of the life cycle is forecast. A *growth curve* is an empirical model of the evolution of a quantity over time. In this article, we model the disciplinary development stage on the basis of the *Gompertz curve*.

The cumulative number of articles represents the total number of articles achieved in the works of research and development of a discipline as of estimation, that is, all the productions of research and development from the emergence of a discipline to the point of estimation. As the cumulative number of articles can show the developing stages of a discipline it is used to model a disciplinary development stage, when Gompertz curve, can be used.

A disciplinary development stage using the Gompertz curve is

$$y(t) = La^{b^t}, \tag{3-1}$$

where a, b, L are constants; t is time; y is the cumulative number of articles at t.

If $0 < a < 1$, $0 < b < 1$, then $y \to 0$ in case of $t \to -\infty$, and $y \to L$ in case of $t \to \infty$, which means the value of a variable y changes between 0 and L; L is an asymptote. Figure 2 shows the disciplinary development stage curve according to the cumulative number of articles.

Modelling a disciplinary development stage by using the Gompertz curve, however, doesn't represent the development stage model this paper focuses on and hence the following operations should be done. If we take y to be a function of t, we obtain the formula

$$y'(t) = y(t)\ln(a)\cdot\ln(b)\cdot b^t . \tag{3-2}$$

If natural logarithm is taken to formula (3-1), then we obtain the formula

$$b^t = \frac{\ln\frac{y(t)}{L}}{\ln(a)} .$$

Substituting this into formula (3-2), we get

$$y'(t) = y(t)\cdot\ln(b)\cdot\ln\frac{y(t)}{L} . \tag{3-3}$$

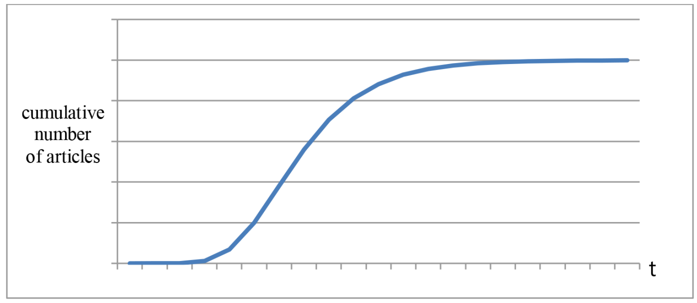

Figure 2: Disciplinary Development Stage Curve According to the Cumulative Number of Articles.

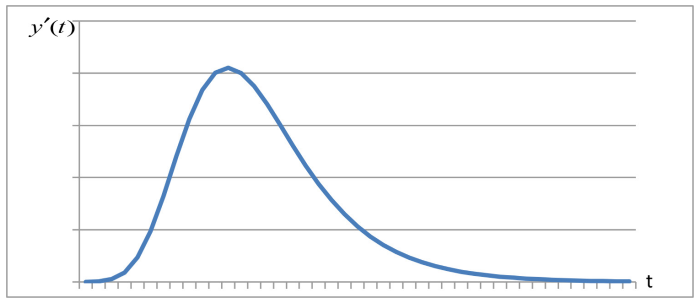

Figure 3: The Curve of Gompertz Differential Equation.

As we see from formula (3-3), for all the y values between 0 and L except for $y(t) = 0$, $y(t) = L$, y' is not equal to zero. Therefore, modelling doesn't take the maximum and minimum value between these two extrema and its change is monotonic. The curve type of Gompertz differential equation is shown in Figure 3.

The curve type of the Gompertz differential equation is similar to the theoretical one of the disciplinary development stage. Even if the coefficient L of Gompertz differential equation is set to 1, the curve type never changes and as the value of a comes nearer to zero, the graph starts at the point zero and the length of the emerging period shown in the theoretical curve gets longer. The value of b is taken within the interval (0,1) and as it gets nearer to 1, the time length of the curve becomes extended. Thereby, the coefficient b is selected to decide the span of a disciplinary development stage. On the other hand, the curve of the Gompertz differential equation does not represent the maximum number of articles of a disciplinary development stage. So, we introduce a new index k, suggesting a mathematical model that represents a disciplinary development stage

$$\hat{y}(t) = k\cdot a^{b^t}\cdot\ln(b)\cdot\ln\left(a^{b^t}\right) , \tag{3-4}$$

where $\hat{y}(t)$ is the number of articles at t and $0 < a < 1$, $0 < b < 1$, $0 < k$.

Formula (3-4) represents the theoretical features of a disciplinary development stage, which is called a *Disciplinary Development Stage Model*. Model coefficients are decided in the following way. Consider that time series data of the articles that show the research result of a discipline are obtained as in Table 1.

Then, the model coefficients can be decided by the formula

$$\min_{a,b,k,t} (\hat{y}(t) - Le_t)^2$$
$$s.t.\ \hat{y}(t+i) = Le_{t+i},\ \ (i = 1, 2, \dots, n) \qquad (3\text{-}5)$$
$$0 < a < 1, 0 < b < 1, 0 < k, 0 < t$$

Review of a disciplinary development model in the aspects of Scientometrics

Classification of disciplines

To classify the disciplines in the aspect of Scientometrics we take as a data group all articles of the scientific journal 'Scientometrics' during 2016 and 2018. This data group includes 160 articles of 2016, 185 articles of 2017 and 160 articles of 2018. Using the research topic classification methodology and science mapping program 'VOSviewer_1.6.10', we classify research topics recorded in the 'Scientometrics' journal.

As a result of classification, there are 30 research topics classified in the aspect of Scientometrics in 2016 (Figure 4) and 34 topics respectively in 2017 and 2018. Based on the classified topics, we select disciplines in the aspects of Scientometrics in association with experts.

The disciplines are made up of 'Scientific collaboration analysis in terms of peer review', 'Scientific collaboration analysis in terms of citation network analysis', 'Collaboration analysis in terms of citation network analysis', 'Scientific collaboration analysis in terms of co-authorship analysis', 'Collaboration analysis in terms of co-authorship analysis', 'A method for bibliometrics indicator', 'A method for research productivity in Scientometrics', 'Scientific collaboration network and collaboration pattern', 'A method for combination of scientific paper in bibliometrics', 'A method for research output growth in bibliometrics', 'A method for journal impact factor in bibliometrics', 'A method for analyzing academic publisher's gender' and 'Scientific collaboration analysis'.

Selection of disciplines

Of selected ones, we should conclude disciplines to be used for an applicative review of the disciplinary development stage. To do so, we should estimate if each selected discipline could represent its developing stages in terms of the related articles. If so, that discipline is the ideal one to be used for the review of a development stage model. To estimate the disciplines, keywords for each discipline are defined in Table 2.

Based on the keywords for each discipline, we sort out the related articles in the international academic paper database at Sci-tech Complex, DPRK. We imagine these sorted articles represent all the research output related to the discipline. The result of sorting articles in terms of the keywords is shown in Table 3.

With the number of sorted articles, we analyze the developing stages of the discipline. As the result of analysis, it is estimated that 'scientific collaboration analysis in terms of citation network',

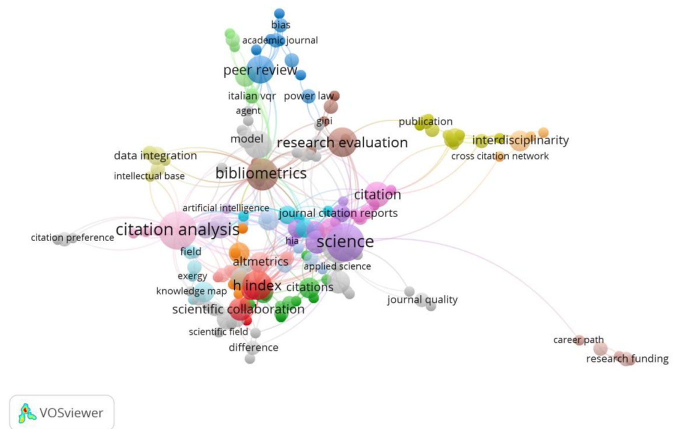

Figure 4: Classification of Research Topics in the Aspects of Scientometrics in 2016.

Table 1: Time Series Data of Articles.

Time	t	t+1	…	t+n
Number of articles	Le_t	Le_{t+1}	…	Le_{t+n}

'a method for combination of scientific paper in bibliometrics' and 'a method for research output growth in bibliometrics' are too insufficient in observed data to properly represent the developing tendency of the discipline. So, we base this to accept disciplines that cannot represent the developing stages due to lack of basic data and that have similar contents. As a result, the disciplines are selected for the applicative possibility review of a disciplinary development stage.

Applicative possibility of a development stage model

With the earlier selected nine disciplines of the aspects of Scientometrics taken as an object, we estimate whether the development stage model suggested can represent the development stage curve of each discipline. These nine disciplines are estimated to represent its development stage curve in terms of the number of published articles; see Table 4.

Therefore, if the development stage curves of this article could represent the development stages of 9 disciplines with actual number of published articles, this development stage model would be possible to apply and if not, it is impossible.

To estimate the applicative possibility of a development stage model, we identify the coefficients of the development stage model for each discipline with the number of published articles of disciplines by time series data.

Above all, we decide the development stage model of 'Scientific collaboration analysis in terms of peer review'. Of all 79 articles,

Table 2: Keywords for disciplines.

Sl. No	Discipline	Keywords (English)
1	Scientific collaboration analysis	Scientific, collaboration, article
2	Scientific collaboration analysis in terms of peer review	Peer review, scientific, collaboration
3	Scientific collaboration analysis in terms of citation network analysis	Citation network, scientific, collaboration
4	Collaboration analysis in terms of citation network analysis	Citation network, collaboration
5	Scientific collaboration analysis in terms of co-authorship analysis	Co-authorship, scientific collaboration
6	Collaboration analysis in terms of co-authorship analysis	Co-authorship, collaboration
7	A method for bibliometrics indicator	Bibliometric indicator, research
8	A method for research productivity in Scientometrics	Scientometric, research, productivity
9	Scientific collaboration network and collaboration pattern	Scientific, collaboration network, collaboration pattern
10	A method for combination of scientific paper in bibliometrics	Bibliometric, scientific paper, combination
11	A method for research output growth in bibliometrics	Bibliometric, research output, growth
12	A method for journal impact factor in bibliometrics	Bibliometric, journal, impact factor
13	A method for analyzing academic publishers' gender	Academic, publisher, gender,

Table 3: Number of Discipline-Related Articles.

Sl. No	Discipline	Number of articles	Period
1	Scientific collaboration analysis	456	1992~2019
2	Scientific collaboration analysis in terms of peer review	79	1994~2018
3	Scientific collaboration analysis in terms of citation network analysis	35	2003~2019
4	Collaboration analysis in terms of citation network analysis	86	1998~2019
5	Scientific collaboration analysis in terms of co-authorship analysis	74	1992~2019
6	Collaboration analysis in terms of co-authorship analysis	134	1992~2019
7	A method for bibliometrics indicator	318	1983~2019
8	A method for research productivity in Scientometrics	169	1990~2019
9	Scientific collaboration network and collaboration pattern	57	1998~2019
10	A method for combination of scientific paper in bibliometrics	32	2001~2019
11	A method for research output growth in bibliometrics	19	2006~2019
12	A method for journal impact factor in bibliometrics	163	1984~2019
13	A method for analyzing academic publishers' gender	49	1993~2019

we sort out the number of published articles by year to make up 25 time series data. On the basis of these time series data, we determine the coefficients of a development stage model (Table 5).

As a result, it is decided that a = 1E-20, b = 0.79, k = 82 (decided by approximation). Then, by analysing the development stage model and time series data, it is estimated that the mean square deviation between the value (predicted value) in terms of a development stage model and time series data value (observed value) is 0.3, where 25 sample nodal points are taken and the sample maximum value is 9. Herein, the mean square deviation is defined as follows.

First of all, if the predicted value in terms of a development stage model is $\hat{y}(t)$, the observed value of time series data is Le(t) and if time series nodal point is n, then Bl(t) is defined as

$$Bl(t) = \frac{\sum_{i=0}^{2} Le(t+i)}{3}, t = 1, \cdots, n-2 \quad (4\text{-}1)$$
$$Bl(t) = \frac{Le(n-1) + Le(n)}{2}, t = n-1$$
$$Bl(t) = Le(n), t = n.$$

Next, the mean square deviation Er is estimated by:

Table 4: Disciplines for Applicative Possibility Review of a Development Stage Model.

Sl. No.	Discipline
1	Scientific collaboration analysis
2	Scientific collaboration analysis in terms of peer review
3	Collaboration analysis in terms of citation network analysis
4	Collaboration analysis in terms of co-authorship analysis
5	A method for bibliometrics indicator
6	A method for research productivity in Scientometrics
7	Scientific collaboration network and collaboration pattern
8	A method for journal impact factor in bibliometrics
9	A method for analyzing academic publisher's gender

$$Er = \frac{\sqrt{\sum_{t=1}^{n}(\hat{y}(t)-Bl(t))^2}}{n} \quad . \tag{4-2}$$

In the same way as above, we decide the development stage models of all the disciplines. The development stage models of each discipline are shown in Table 6. Then, we compare and analyze the development stage model and time series data. Figure 5 shows the relationship between the obtained development stage model and the actual curve.

By deciding the development stage curves of all the disciplines and comparing with time series data and analyzing it, we estimate that the development stage suggested here represents the development stages of these nine disciplines successfully, which means that a disciplinary development stage can be estimated by the suggested development stage model.

Table 5: A Development Stage Model of 'Scientific Collaboration Analysis in Terms of Peer Review'.

Year	t	Predicted value	Observed value	Smooth value	Deviation from smooth value
1994	1	0.0	1	1.0	1.00
1995	2	0.0	1	1.3	1.78
1996	3	0.0	1	1.0	1.00
1997	4	0.0	2	0.7	0.44
1998	5	0.0	0	0.7	0.44
1999	6	0.0	0	1.0	0.99
2000	7	0.0	2	1.7	2.70
2001	8	0.1	1	1.3	1.46
2002	9	0.4	2	1.3	0.82
2003	10	1.1	1	2.0	0.85
2004	11	2.1	1	3.7	2.38
2005	12	3.5	4	4.3	0.76
2006	13	4.8	6	5.3	0.24
2007	14	6.0	3	3.7	5.48
2008	15	6.8	7	5.3	2.09
2009	16	7.1	1	5.3	3.12
2010	17	7.0	8	8.0	0.99
2011	18	6.6	7	7.3	0.54
2012	19	6.0	9	6.3	0.12
2013	20	5.3	6	3.7	2.61
2014	21	4.5	4	3.0	2.40
2015	22	3.8	1	2.3	2.30
2016	23	3.2	4	3.7	0.21
2017	24	2.6	2	3.5	0.73
2018	25	2.2	5	5.0	8.05

Table 6: Development Stage Model of Each Discipline.

Sl. No	Discipline	a	b	k	Number of sample nodal points	Mean square deviation	Sample maximum value
1	Scientific collaboration analysis	1.65E-08	0.79	400	27	1.0	47
2	Scientific collaboration analysis in terms of peer review	1E-20	0.79	82	25	0.3	9
3	Collaboration analysis in terms of citation network analysis	1E-6	0.87	180	22	0.4	12
4	Collaboration analysis in terms of co-authorship analysis	1E-08	0.91	500	28	0.6	19
5	A method for bibliometrics indicator	1E-08	0.94	2000	37	0.9	36
6	A method for research productivity in Scientometrics	1E-08	0.9	500	30	1.0	28
7	Scientific collaboration network and collaboration pattern	1E-6	0.86	100	21	0.2	7
8	A method for journal impact factor in bibliometrics	1E-10	0.91	400	36	0.3	17
9	A method for analyzing academic publisher's gender	1E-10	0.86	80	27	0.1	6

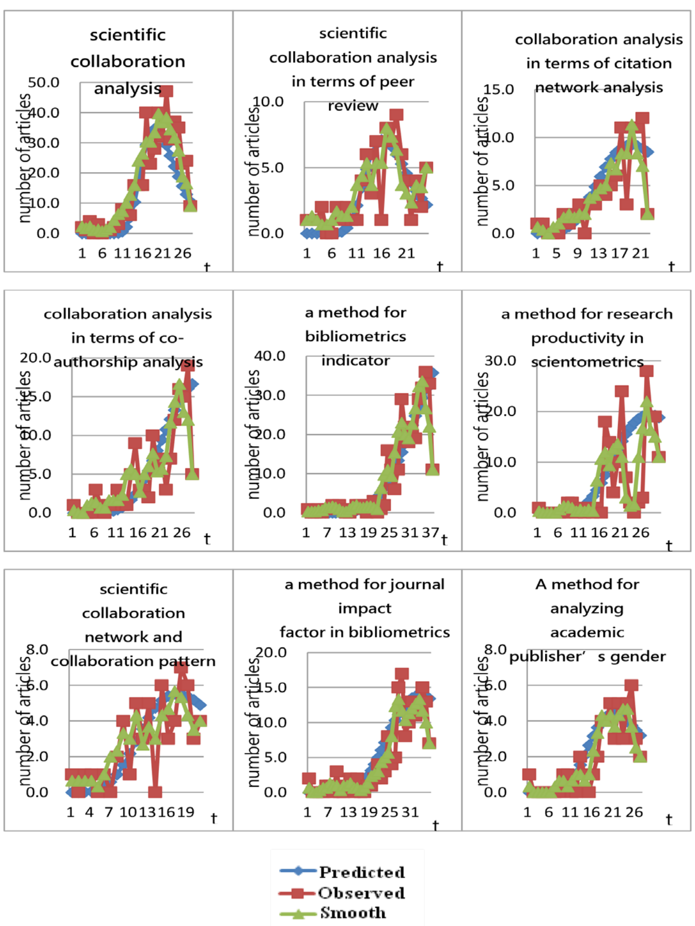

Figure 5: Development Stage Curve in Terms of a Life Cycle Model.

CONCLUSION

This study suggests the theory of a disciplinary development stage, and then, a development stage model by extending the theory of product and technology development stage. From the point of view of a disciplinary development, we base the disciplinary development stage model on the number of published articles and the growth curve model.

In this study, we take the disciplines of the aspects of Scientometrics as an object to review the applicative possibility of the development stage model suggested. As a result, we have indicated through experiment that the development stage model of this study can represent a disciplinary development stage.

A disciplinary development stage model shows the developing features of disciplines and hence the current development stage of disciplines can be estimated and the future development process forecast on the basis of it.

These kind of information will be used effectively to work out a scientific and technological policy and strategy for the development of science and technology in a country or area. It also has a great significance in the investigation of research orientation of individual group of researchers and the selection of research tasks.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Cite this article: Jong JB, Choe M, Drakopoulos V, Ri SI. An Evaluation Method for Modelling a Disciplinary Development Stage. Journal of Data Science, Informetrics, and Citation Studies. 2023;2(2):102-9.