Scientometric Study of Product Lifecycle Management International Conferences: A Decade Overview

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Abstract. PLM International Conference proceedings focussing on the field of Product Lifecycle Management have made a lot of advancements in the last 12 years. Since 2003, 11 conferences on PLM have taken place but a systematic analysis of the evolution in PLM literature is, however, not available at the moment. This study proposes an analysis of the growth of the scientific literature on PLM over a 10 year period using standard bibliometric techniques. A total of 565 scientific papers have been examined to find out about the growth of literature, authorship pattern, geographical & organizational distribution of papers, citation count and most frequently occurring keywords. The findings of this study give an insight into the evolution of literature on PLM by means of quantitative & qualitative analysis and provide useful information to scientists wishing to undertake work in this field.

Keywords: Product lifecycle management · Bibliometrics · Citation analysis · PLM conference proceedings

1 Introduction and Literature Review

PLM IC (Product Lifecycle Management International Conference) proceedings which are furthering research in the field of PLM have made a lot of advancements in the past 12 years. The first international conference on PLM took place in 2003 as an international symposium in India. The huge success of this symposium and growth of interest in the field of PLM led to running of further events as international conferences [1]. Since 2003, PLM conferences have been bringing together researchers, developers, and users of PLM involved in product innovation, product development, and product delivery together under one forum to share recent developments, shape the future of this field and advance the science and practice of enterprise systems development [2]. The conference series began to give PLM, as a research area, an identity and a community in the academic world. PLM holds the promise of seamlessly integrating and

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making available all of the information produced throughout all the stages of a product's lifecycle to everyone in an organization along with key suppliers and customers [1]. The international conferences have been held 11 times and have published 565 papers since 2005 [2].

The present paper provides a bibliometric analysis of the PLM IC proceedings for the period 2005–2014. Bibliometrics is based on the enumeration and statistical analysis of scientific output in the form of articles,Publications, citations, patents and other more complex indicators. It is an important tool to evaluate research activities, laboratories and scientists as well as the scientific specialisations and performance of countries [3]. The word 'bibliometrics' first appeared in 1969 in Alan Pitchard's article on statistical bibliography [4]. The term started getting widely used with the works of Lotka, Bradford and Zipf in the early 20th century [5]. There are very few research papers that carried out the bibliometric analysis of PLM in the past. A. Varandas Junior et al. presented a bibliometric analysis of literature on 'Product Lifecycle Management, Product Development Process and Sustainability & Their Interfaces [6]. The analysis was performed using various softwares and web of science database over a period of 5 years (2006–2010). Nappi and Rozenfeld also undertook a study on bibliometric analysis of research papers based on PLM in the paper entitled 'Sustainability Performance Indicators for Product Lifecycle Management' [7]. A research paper that investigates the contribution of PLM IC proceedings in the evolution of research work in PLM field is currently not available. The aim of this paper is to provide a review of the international conference proceedings on PLM over a 10 year period by means of bibliometric analysis.

The organisation of the research paper is done in a systematic way. Firstly, the methodology of extraction and treatment of data from the research papers to perform the analysis is described. Afterwards, outcomes of the bibliometric analysis of the research papers by qualitatively and quantitatively means are described and presented in the form of tables and figures. These outcomes help us perceive the evolution of the research in the field of PLM over a 10 year period. Lastly, the findings and conclusions of the paper are highlighted.

2 Bibliometric Methodology

2.1 Introduction

Bibliometrics is quantitative study of various aspects of literature on a topic and is used to identify the pattern of publication, authorship, and secondary journal coverage to gain insights into the dynamics of growth of knowledge in the areas under consideration [8]. The bibliometric study has been performed using the large database of PLM IC proceedings available on the www.plm-conference.org website. Though there are a lot of websites (Science Direct, Scopus, Google Scholar etc.) that provide huge database to perform bibliometric analysis of PLM, PLM IC proceedings website has been chosen to do the analysis as it is a platform that draws together people from all over the world pertaining to the field of PLM and provides large volume of data in a systemized and organised manner which is useful in doing fast analysis. In this study,

bibliometric analysis of PLM for the period 2005–2014 has been performed. The analysis is performed from the year 2005 in which the International Conference proceeding on PLM took place in Lyon, France.

2.2 Methodology for Citation Count and Assignment of Contribution

Furthermore, Google Scholar has been used to find out the keywords (whenever they were not available in the PLM IC database) and citation count of the papers as in contrast to websites like Web of Science and Scopus, Google Scholar provides a comprehensive database covering conference proceedings, journals, books, dissertations, and preprints [9]. The citation count of papers has been found out by using title and author search function of the Google Scholar. If the search engine doesn't list the searched research paper in the result, then the citation count of that paper is taken as zero. In sum, Google Scholar has been found out to be a very quick and efficient way to know the citation count of papers as it indexes a huge list of technical literature.

In this study, whenever a research paper is written by several countries or organizations in partnership, then the method of integer count rather than fractional count is adopted to assign the contribution of that particular country or organization. Integer count method has been preferred over fractional count method as it is in agreement with the principles of microanalysis. Also, integer count method is easier to implement and interpret [10]. Thus, in our study, for example, if both France and India published a paper in collaboration, then according to our methodology, France published one paper and India published one paper. In a similar way, if two authors (i.e. S. Charles & G. Ducellier) published a paper together, then we say that S. Charles wrote one paper and G. Ducellier wrote one paper. Furthermore, if there are two offices of the same organizations or companies, then they are not considered as two separate entities but counted as one. Lastly, if two organizations (Arts et Métiers Paris Tech, France & University of Michigan, America) published a paper together then we say that Arts et Métiers ParisTech, France published one paper and University of Michigan, America published one paper.

2.3 Database

In order to perform analysis of the large amount of information available on the PLM conference website, a self-developed database was created using Microsoft Excel. The choice of Excel for making the database is based on the fact that it is one of the most famous powerful information management tool for organizing, calculating and visualizing data. The data extracted from all the 565 papers has been put into tabular form encompassing all the available information in 12 different columns, namely, year of publication, title of the paper, name of the authors, number of collaborating organizations, types of organizations, name of the organizations, number of collaborating countries, number of authors per paper, citation count of the paper, host country of the conference proceedings, number of keywords and names of the keywords. In addition to a general table encompassing all the available information, several other tables have

been made to analyse the data and draw conclusions. Data corresponding to these tables have been obtained after some reasoning or further investigation while data for the general table has been retrieved directly from the research papers.

3 Results of the Analysis: PLM International Conference Proceedings (2005–2014)

The analysis of the data extracted from the research papers helps us find out about annual distribution of papers & literature growth, geographical & organizational distribution of papers, authorship patter & degree of collaboration, the citation count of papers and the most frequently occurring keywords.

3.1 Annual Distribution and Growth of Literature

The organization of data obtained from the research papers has helped us visualize the growth of the scientific literature in the field of PLM over a 10 year period. There is a clearly a rise in the scientific literature involving PLM with total number of publications rising from 52 in the year 2005 to 565 in 2014 as shown in Fig. 1. The accumulated number of research papers published by PLM IC proceedings are shown in a year wise manner in Table 1. The row corresponding to total count for the number of countries, authors, and organizations for the period 2005–2014 considers counting the same author, country, and organization more than once as they may have participated more than once in the period 2005–2014.

Table 1. Most relevant data of the PLM IC proceedings for the period 2005-2014

Year	Host City	Host Country	Papers	No of Countries	Authors	Organizations
2005	Lyon	France	52	18	146	63
2006	Bangalore	India	29	9	80	40
2007	Stezzano	Italy	85	25	260	104
2008	Seoul	Korea	45	16	143	54
2009	Bath	UK	68	20	227	86
2010	Bremen	Germany	62	14	183	71
2011	Eindhoven	Netherlands	46	15	128	56
2012	Montreal	Canada	58	19	168	60
2013	Nantes	France	70	23	211	81
2014	Tokyo	Japan	50	18	157	70
Total	–	–	565	177	1703	685

The average number of papers published for the period 2005–2014 has been found to be 56.5 with the maximum number of papers published being 85 in the year 2007 with a participation of 25 countries, 260 authors and 104 organizations and the lowest number being 29 in the year 2006 with a participation of 9 countries, 80 authors and 40

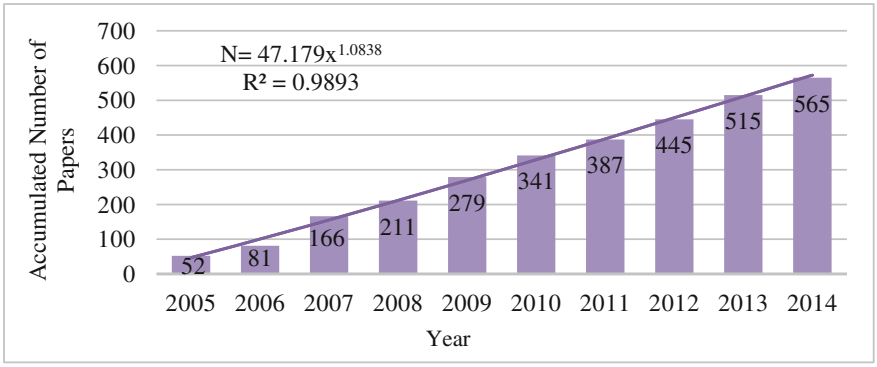

Fig. 1. Accumulated number of papers over a 10 Year Period. N being the accumulated number of papers and x stands for ordinal number of conferences

organizations. Also, the calculated value of variance and standard deviation for the number of papers published over 10 years are 222.05 and 14.901. The fluctuations in the number of published papers might be because of a number of reasons like technological advances, degree of international collaboration, political policy etc.

3.2 Geographical Distribution of Publications

PLM IC proceedings have been attended by 41 countries during the period 2005–2014 with maximum number of contributions coming from France with a total number of 137 papers followed by Germany with 108 papers. Some of the other contributors are as follows: Italy (61 papers), UK (50 papers), USA (41 papers), South Korea (30 papers), Canada (28 papers), Finland (24 papers), India (22 papers), Japan (19 papers), Switzerland (18 papers), Sweden (16 papers), Netherlands (13 papers) and Australia (11 papers).

Therefore, France and Germany have been the major contributors at the PLM IC proceedings during the 10 year period and account for 43.4 % of the total number of published papers. However, PLM based research work is getting a lot of attention and is distributed worldwide. The contribution of countries from all over the world is shown in Fig. 2.

By noticing the distribution of international collaboration between different countries, it is found that the maximum number of collaborations has been found out to be between France & UK with 6 publications, followed by France & USA and France & Canada with 5 publications, and lastly between France & Italy and USA & Japan with 4 publications.

Moreover, the country with the maximum number of international collaborations is France (19), followed by USA (12), Italy (11) and UK (10) and so on. The collaboration between different countries is shown using a network diagram in Fig. 3. In the network diagram, the size of the circles is proportional to number of international collaborations of that country. Thus, France with 19 international collaborations is

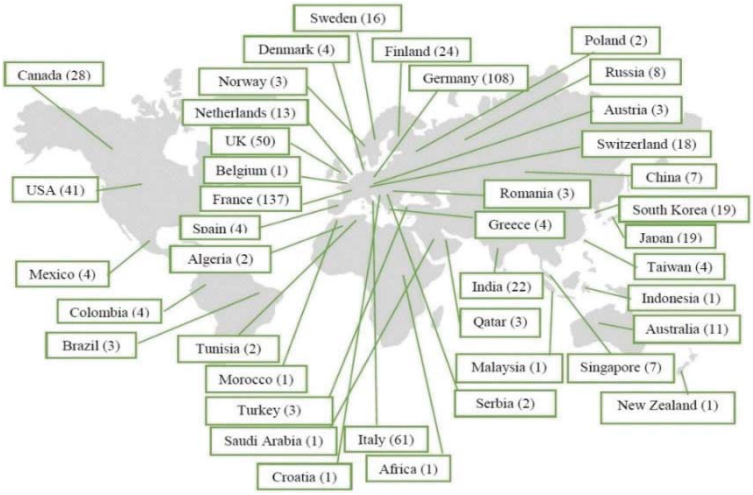

Fig. 2. Geographical distribution of the research papers

depicted in the diagram using the biggest size circle while countries like Morocco, Columbia etc. having only 1 international collaboration have been shown using smallest size circle. It is easy to visualize from the network diagram that France, USA, UK, Italy, Germany, Switzerland are the countries with maximum number of international collaborations.

Lastly, majority of the collaborations are between two countries except for one between 7 countries (France, Italy, UK, USA, India, Korea, and Switzerland) in 2008,

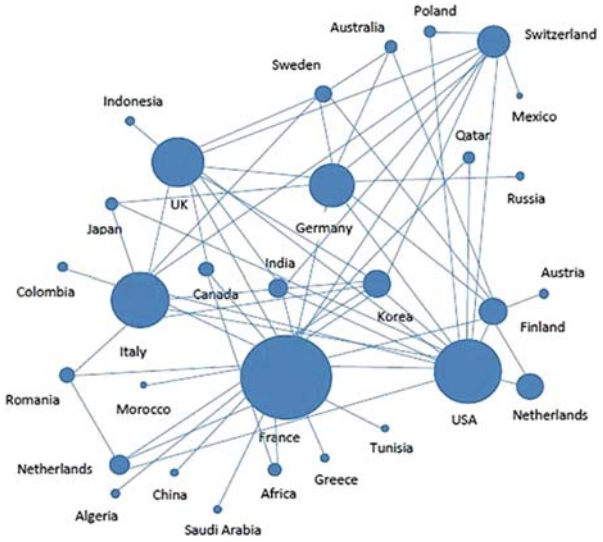

Fig. 3. Network diagram showing collaborations between different countries

one between 4 countries (France, Italy, Netherlands, and Romania) in 2009, one between 3 countries (France, Finland, and Germany) in 2007, one between 3 countries (Poland, USA, and Switzerland) in 2009, one between 3 countries (France, Canada, and Africa) in 2010, and one between 3 countries (France, USA & Qatar) in 2012 & 2013.

3.3 Authorship Pattern and Degree of Collaboration

Collaborative research instead of individualized one is a very important feature of the 21st century. The distribution of authorship (Fig. 4) clearly shows that out of 565 research papers, 521 (about 92 %) of the research papers have been written by multiple authors and only 44 research papers have been written by a single author. Table 2 lists the number of papers written by single & multiple authors per year. Clearly, each year the number of papers written by multiple authors far exceeds the number of papers written by single authors.

Table 2. Degree of Collaboration of authors

Year	No. of Papers	Single Author	Multiple Authors	Degree of Collaboration
2005	52	10	40	0.80
2006	29	3	26	0.90
2007	85	9	76	0.89
2008	45	1	44	0.98
2009	68	2	66	0.97
2010	62	3	59	0.95
2011	46	5	41	0.89
2012	58	2	56	0.97
2013	70	6	64	0.91
2014	50	3	47	0.94
Total	565	44	521	0.92

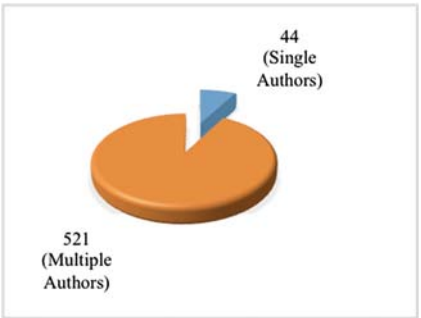

Fig. 4. Pie Diagram of Distribution of Authorship

The degree of collaboration calculated in Table 2 is found out using the mathematical formula (1) given by K. Subramanyam as follows:

$$\text{Degree of Collaboration} = \text{NM}/(\text{NM} + \text{NS}). \quad (1)$$

where NM = No. of papers written by multiple authors and NS = No. of papers written by single authors. The overall degree of collaboration for a period of 10 years is found out to be 0.92 which clearly shows the importance of collaborative research. Furthermore, Fig. 5 shows that the maximum number of the research papers (176) have been written by three authors in collaboration and is followed by four author (132) and two author case (129). As the number of co-authors become more than 5, the number of papers become very few in number (26).

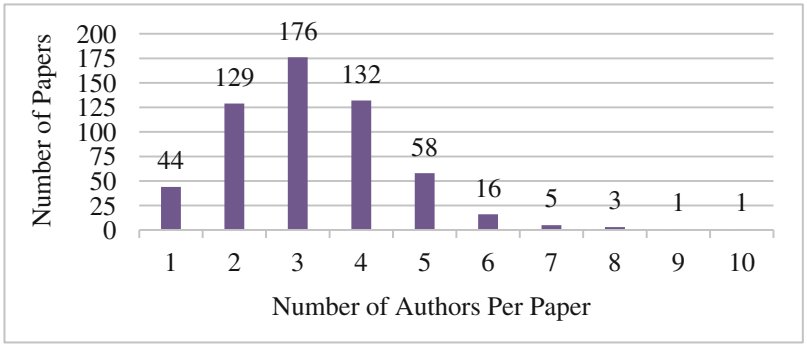

Fig. 5. Distribution of Co-Authorship

3.4 Organizational Distribution of Papers

As far as the organizations are concerned, University/Research Institutions (RI) turn out to be major contributors with 74.2 % of the research papers (419 papers) coming from them. In contrast to this, only 9.4 % of the research papers (53 papers) have been contributed by companies while contribution from company-university/research Institutions collaboration amount to 16.5 % (93 papers). Figure 6 shows that throughout the

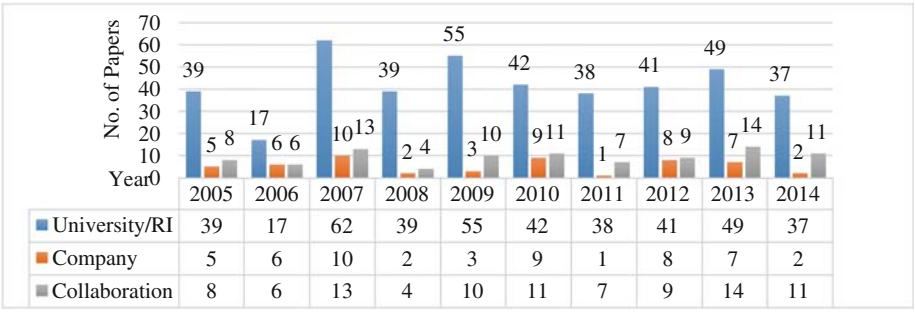

Fig. 6. Distribution of papers according to publishing organizations

10 year period universities and research institutions have contributed significantly in the growth of scientific literature in the field of PLM while the number is quite low for companies.

Among the twenty of the most productive organizations, seven universities come from France alone. All the major contributors are universities with Université de Technologie de Compiègne & Politecnico di Milano sharing the top place and contributing the maximum number of papers (21). The top 20 most productive organizations alone accounts for 48.9 % (276 papers) of the total number of contributions.

3.5 Citation Analysis

Google Scholar has been chosen to perform the citations analysis of research papers because of its comprehensive database. The research papers have been searched in Google Scholar by using combination of title of the paper and author names to get an accurate count of number of citations. Furthermore, citation count for a research paper is taken as zero if the paper doesn't appear in the search results of Google Scholar. Table 3 lists the number of citations received by total number of papers (as on 26th March, 2015) published each year with maximum number of citations being 300 for 52 research papers in the year 2005. In sum, a total of 1107 citations are obtained by 565 research papers over a 10 year period with average number of citations per research paper being 1.96.

Table 3. Citation Pattern

Year	No. of Articles	No of Citations	Average No. of Citations per Article
2005	52	300	5.769
2006	29	37	1.276
2007	85	142	1.670
2008	45	96	2.133
2009	68	209	3.074
2010	62	75	1.210
2011	46	84	1.826
2012	58	95	1.638
2013	70	59	0.843
2014	50	10	0.200
Total	565	1107	1.959

3.6 Keywords Classification

Keywords mentioned in the research papers aid us in getting an insight into the focus of the research field of the papers. As there is no standard way in which keywords are mentioned, the authors vary the number of keywords used to outline the paper according to their own criterion while some of the authors don't mention it at all [11, 12]. Similar pattern has been observed while performing analysis of the 565 research papers of PLM IC proceedings. Some of the authors didn't mention the keywords at all [13] while

others varied the number of keywords by large amount (the lowest number being 2 while the highest number going up to 23). The total number of keywords for all the 565 papers is calculated to be 2068 giving an average of 3.66 keywords per paper.

Taking into consideration the diversity of the keywords found, the approach used in this research paper for classification of the keywords is to take into account only the first three keywords mentioned by the authors as they describe the contents of the research paper precisely. However, the shortcoming of this approach is that not all the research papers of the PLM IC proceedings have keywords.

In order to calculate the rate of occurrence of keywords, NVivo 10 [14] software has been used. While performing word frequency query in NVivo, stop words such as conjunctions or prepositions are not taken into account as they are not meaningful in the analysis. Also, 'exact matching criteria' for the words is selected while performing word query analysis. If a keyword is made of more than one word, then the space between individual words of that keyword is omitted before running query otherwise NVivo breaks the keyword into separate words and gives rate of occurrence of individual words of that keyword. For example, the keyword 'Product Lifecycle Management' is written as 'ProductLifecycleManagement' before performing the query otherwise 'Product Lifecycle Management' is broken into 'Product', 'Lifecycle' and 'Management' by the software and the final result that is obtained is rate of occurrence of each of the individual words rather than that of 'Product Lifecycle Management' altogether. The principal outcomes given by the software are the most frequently occurring words, their citation count and their weighted percentage as shown in Table 4. As can be seen from the table, keyword 'Product Lifecycle Management' occupies the top place with a citation count of 53 followed by the keywords 'PLM', 'Modeling' and so on.

Apart from using NVivo, Wordle has been used to create word clouds using the first three of the author's keywords as the input text (Fig. 7.). The clouds give greater prominence to words that appear more frequently in the input text, thus helping us easily visualize the words appearing most frequently in the submitted text.

Table 4. Top 10 most frequent keywords by taking into account first three author's keywords

Number	Word	Rate of Occurrence	Weighted Percentage (%)
1	Product Lifecycle Management/PLM	93	9.12
2	Modeling	26	2.55
3	Knowledge Management	18	1.76
4	Product Lifecycle	12	1.18
5	Product Development	9	0.88
6	Ontology	9	0.88
7	PLM Implementation	8	0.78
8	Production Management	8	0.78
9	Production Engineering	8	0.78
10	Interoperability	8	0.78

Fig. 7. Word Cloud made by using first three author's keywords

4 Findings and Conclusions

This study carried out a bibliometric analysis of 565 papers published by the PLM IC proceedings for the period 2005–2014. The analysis helped us find out the growth of literature over 10 years, the geographical & organizational distribution of papers, authorship pattern, citation count of papers and the most frequently occurring keyword.

Though the number of articles published per year is not consistent and varies from year to year, there is clearly a rise in the scientific literature involving PLM with total number of publications rising from 52 in the year 2005 to 565 in 2014. The average number of papers published for the period 2005–2014 has been found out to be 56.5. Geographical distribution of the papers shows that France and Germany are the major contributors at the PLM IC proceedings during the 10 year period and account for 43.36 % of the total number of published papers. The maximum number of collaborations has been found out to be between France & UK with 6 publications and the country with the maximum number of international collaborations is France with 19 tie-ups in total. Furthermore, 521 (about 92 %) research papers have been written by multiple authors and only 44 research papers have been written by single author. The most dominant is found out to be the 3 authors' case. Hence, collaborative research is prominent in this field with an average degree of collaboration of 0.922. Throughout the 10 year period, universities and research institutions have contributed significantly in the growth of scientific literature in the field of PLM while the number is quite low for companies. Universities/Research institutions account for 74.16 % (419) of the total research papers while only 9.38 % (53) of the research papers are contributed by companies. Citation analysis shows that a total of 1107 citations have been obtained by 565 research papers over a 10 year period leading to an average number of citations per research paper of 1.959. Lastly, there is a lot of diversity in the number of keywords provided by the authors. Some of the authors didn't mention the keywords at all while others varied the number of keywords by a large amount (the lowest number being 2 while the highest number going up to 23). The total number of keywords for all the 565 papers is calculated to be 2068 giving an average of 3.66 keywords per paper.

The findings of this study provide us with useful information about the state of PLM based research in the world. PLM is an evolving discipline that is attracting

attention from all over the world. Results of the study depend on the chosen data source. The methodology mentioned in this paper has been applied to database of PLM IC proceedings for a period of 10 years only to arrive at meaningful results in order to get an insight into the evolution of research work done in the field of PLM. It would be worth applying this methodology to other databases and time periods to arrive at comparative results. For the time being, we can say that this study gives a broad view of PLM IC proceedings effort to promote research work in the field of PLM by bibliometric analysis and will prove very useful to perform similar bibliometric studies in the field of PLM in the near future.

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