Bibliometric analysis of the term ‘Three-Dimensional Concurrent Engineering’

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Abstract. Three-dimensional concurrent engineering (3DCE) concept provides a new approach for integrating product, process, and supply chain design. The opportunities to shorten product development lead time and time to market eventually, increase product variant and quality, and reduce product development costs become a concern. However, the 3DCE approach is not yet comprehensive since the researches are continuing and growing. This article provides a bibliometric literature review on 3DCE as a term and concept through mainly Scopus database and Mendeley software for managing and resuming the references. After manual filtering and reading we conclude 39 articles strongly related to the term of 3DCE. Finally, we classified the articles based on its keywords into two clusters of words using VOSviewer software. Moreover, we found that ‘supply chain’, ‘product development’, and ‘product design’ were the most frequently used for keywords, titles, or abstracts that represented the research stream or the researcher’s background.

1. Introduction
In the last two decades, the solutions for minimizing time to market, increasing product variants, minimizing product cost, and optimizing product quality is integrated product development. Integration on the product, manufacturing, and supply chain design has been done partially in pairs, for example, concurrent engineering (product – manufacturing design), product – supply chain design, and process – supply chain design. Three-dimensional concurrent engineering spreads concurrent engineering (CE) concept by adding the design and development of supply chain capabilities.

Several researchers, such as [1], [2], [3], and [4], had reviewed the research contributions on 3DCE. Ellram et al. provided a literature review to support the theoretical lens for 3DCE and ground future research. They found literature called complementary 3DCE literature, which they believed very important to shape 3DCE theory. They listed the literature along with its literature stream and contributions to 3DCE in detail. Finally, they found only 13 literatures that coordinated all three dimensions that directly supported the efficacy of 3DCE as proposed by Fine.

Castellano and Dolado presented a comprehensive review of structures alignment of 3DCE for mass customization. They aimed to identify and structure critical research issues and research methods in 3DCE area. They presented the mapping of 3DCE literature based on their research issues, models and frameworks, methods and methodologies, tools, and its domains. Using 15 key references and 44
references as complementary, they conclude that many papers focused on framework development without further theory-testing validation.

Shahbazi et al. conducted a comprehensive literature review which classified into the research streams. The classified research streams are inventory allocation problem, concept of product architecture, product and supply chain structure (such as responsive supply chain or modular supply chain), other considerations (such as legal, environmental, macroeconomic aspect, product safety and social responsibilities), supplier’s key role in integrated product development, and methodologies for the modelling and implementation of 3DCE. Moreover, they also reviewed the literature based on research methods and industry studies. Finally, using 29 references, they pointed out the need to grow the industry sectors domain for 3DCE implementation-oriented studies. They proposed organising the business environment complexities and uncertainties for another future research proposition.

Ilhami et al. conducted a 3DCE mathematical model literature review which specifically focused on references with a mathematical model for solving the trade-offs in the 3DCE decision making. They found 35 references divided into 4 groups of dimensions and 7 subtopics. They pointed out the lack of references on the 3DCE mathematical modelling which were only 5 references.

Indistinct to above literature reviews, we propose a bibliometric analysis. Bibliometric analysis is generally used in scientific disciplines and focuses on a quantitative study of journal papers, books or other types of written communication [5], which the much of our conversance no publication has published the bibliometric analysis of the term “three-dimensional concurrent engineering”. Moreover, we use citation rates to assess the academic quality of journals or authors.

The organisation of the paper is as follows. Section 2 describes the 3DCE definition. Section 3 presents the bibliometric analysis methodology, including the method steps. Section 4 presents the results and discussions. Finally, the last section presents the recommendations, conclusions, and limitations of the study.

2. 3DCE Definition
Charles H. Fine [6] introduced the term “Three-Dimensional Concurrent Engineering” that in early product design phase considered different aspects of the design, process & supply chain, configuring the supply chain, and simultaneously organizing products & processes. Moreover, he pointed out the importance of the temporary competitive advantages which prompt companies to see advantage opportunities from the whole supply chain. He believed that the company could obtain temporary advantages from inside or outside the company. Thus, the 3DCE approach creates the opportunity for temporary advantages higher. If you don’t wish to use the Word template provided, please set the margins of your Word document as follows.

However, there is no confirmed definition issued by formal institutions related to 3DCE. Moreover, in the term of the acronym of three-dimensional concurrent engineering, we discover at least three acronyms ‘3DCE’, ‘3-DCE’, and 3’D-CE’. Moreover, there is no confirmation upon the particular acronym for “Three-Dimensional Concurrent Engineering” whether ‘3DCE’, ‘3-DCE’, or ‘3D-CE’.

The main reason for 3DCE’s emergence is insufficient for concurrent engineering to ensure competitive advantages [6]. As a product designer, the questions about what must be added to make the product in line with the current or future market? Fine [6] believed the answer to this question occupied in the configuration design of the supply chain. To support the 3DCE theory, concurrent literature on two dimensions such as “Concurrent Engineering (CE)” or product/process linkage, process/supply chain linkage, and product/supply chain linkage. Multi-functional teams, suppliers, and customers are required in 3DCE in the early design process [7, 8].

3. Methodology
We conducted this research using the five-steps method proposed by Fahimnia et al. [9]. The five-steps are described in more detail as follows.
3.1. Defining search keywords
This literature exploration was conducted on May 2019 using the keywords ‘3DCE’, ‘3-DCE’, ‘3D-CE’, ‘Three-Dimensional Concurrent Engineering’, and ‘Product Process and Supply Chain’. As we focus on the 3DCE term, we excluded 3DCE supporting or complementary literature such as ‘CE’ or ‘Concurrent Engineering’ and other 2D literature.

3.2. Initial search results
We conducted the initial search using Scopus and Publish or Perish Software (PoP) with both using Scopus Database. PoP software is easier to use, but search filters limited to authors, affiliations, publication name, title words, and keywords. Meanwhile, the Scopus search has extra filters such as abstract and subject areas. Moreover, we can exclude irrelevant subject areas. Table 1 shows the initial results of both searches. For accuracy reason, we searched the literature using one keyword at a time. The summarize of all keyword searches are presented in Table 1.

3.3. Refinement of the search results
We refined the search using filters and then inspect each reference one by one manually. Furthermore, we examined all remaining references and excluded unrelated references manually. We combined all the results into a set of search results and found 39 suitable references in total, which Table 2 shows the refinement results.

3.4. Compiling the initial data statistics
The refinement search results downloaded and exported to the CSV format to include all required information (metadata) to be processed in VOSviewer software. The required information consists of authors, document title, year, citation count, access type, publisher, abstract, author keywords, and index keywords. The top five of most cited of the 39 references and the number of references for every two years are presented in Table 3 and figure 1 respectively. We may know from Figure 1 that the oldest reference (which is 2001) and the newest reference (which is 2018).

| Table 1. The initial (unrefined) search comparison of Scopus Search and PoP |
|-----------------------------------------------|
| Search keywords                             | Scopus Search Engine | PoP  |
| 3DCE                                         | 21                  | 29   |
| 3-DCE                                        | 7                   | 26   |
| 3D-CE                                        | 22                  | 170  |
| Three-Dimensional Concurrent Engineering     | 10                  | 13   |
| Product Process and Supply Chain             | 16                  | 5    |

| Table 2. Refinement of the search results |
|-------------------------------------------|
| Search keywords                           | Scopus Search Engine | PoP |
| 3DCE                                      | 9                    | 10  |
| 3-DCE                                     | 2                    | 3   |
| 3D-CE                                     | 3                    | 4   |
| Three-Dimensional Concurrent Engineering   | 9                    | 13  |
| Product Process and Supply Chain          | 15                   | 5   |
Table 3. Top five most cited 3DCE references

| No | Authors | Title                                                                 | Year | Cited by |
|----|---------|----------------------------------------------------------------------|------|----------|
| 1  | Petersen K J Handfield R B and Ragatz G L  | Supplier integration into new product development: Coordinating product, process and supply chain design | 2005 | 630      |
| 2  | Wang G Huang S H and Dismukes J P        | Product-driven supply chain selection using integrated multi-criteria decision-making methodology | 2004 | 376      |
| 3  | Fixson S K                                | Product architecture assessment: A tool to link product, process, and supply chain design decisions | 2005 | 312      |
| 4  | Salvador F Forza C and Rungtusanatham M  | Modularity, product variety, production volume, and component sourcing: Theorizing beyond generic prescriptions | 2002 | 307      |
| 5  | Huang G Q Zhang X Y and Liang L           | Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains | 2005 | 181      |

3.5. Data analysis
We conducted the references searching using the PoP version 7.10.2343.7109 macOS GUI edition on June 24th, 2019. We obtained 243 references in the initial results and 35 references in the refinement results. Meanwhile, we obtained 76 references in the initial results and 38 references in the refinement results using Scopus Search Engine. Finally, we merged the both results and obtained 39 references as the final set of references.

4. Results and Discussions
This study shows that the trend of the references for 3DCE is quite a few. No references more than ten every two years indicate that (see Figure 1). No less than 630 authors have cited the most frequently cited reference published by Petersen et al. [10] (see Table 3).

The 39 references resulted from PoP and Scopus Search Engine is analysed to determine the frequently keywords using VOSviewer software. VOSviewer software is a mapping software using a regulated frequency that can be managed to get the possible output based on the purposes of mapping. Van Eck and Waltman developed VOSviewer software used for clustering the bibliometric and visualizing the results in three different visualizations, network visualization, overlay visualization, and density visualization in 2010.

Keywords mapping is a clustering of keywords and its relation to others. The VOSviewer parameters applied in this study are: co-occurrence type of analysis; all unit of analysis; full counting method; and the number of occurrences was two times. Our most purpose of the study is to know the most keywords

Figure 1. Number of references of each 2 years
used for 3DCE studies. Thus, we then revised the previous mapping using a higher number of occurrences (changed from 2 to 5) and excluded common words for better (fewer keywords) visualization, which presented in Figure 2.

From figure 2 we might see the history of 3DCE, especially the 3DCE acronym, we would notice that at the beginning of 3DCE the acronym was 3-DCE (purple coloured) or 3D-CE (green coloured), but later on from 2012 – current date, it became 3DCE. It also shows keywords such as coordination of product, process, and supply chain (see [10–13]), mathematical models and decision making (see [14,15]) were the most frequent keywords in 3DCE before 2006. During 2007 – 2012, keywords such as product design, product development, and concurrent engineering (CE) were the most common keywords used (see [1,16,17]). While after 2012, the keywords such as 3DCE, supply chain, multi-objective programming and sustainable development were the most frequent keywords used (see [4,18–25]).

Figure 2 shows that the most common keywords used are ‘product development’, followed by ‘product design’ and ‘supply chain’. The keyword ‘product development’ was used in [1,10,16,18,26]. The keyword ‘product design’ was used in [16,17,23]. The last keyword ‘supply chain’ was used in [15,17,18,22,23,25–29]. From the item tab menu in VOSviewer software, we would know that there were two clusters where 3DCE, concurrent engineering, product design, and supply chain were in cluster 1, while decision making, modularity, and product development were in cluster 2. The 3DCE was developed from concurrent engineering along with the awareness of simultaneously the design for the supply chain in the early phase of product design. That is why 3DCE, concurrent engineering, supply chain, and product design are in cluster 1. The keyword 3DCE is nevertheless the smallest total link strength. However, if all keywords such as ‘3DCE’, ‘3-DCE’, ‘3D-CE’, and ‘three-dimensional concurrent engineering’ are combined, they could have a higher number of total link strength.

Figure 2. The overlay visualization of VOSviewer revised output
5. Conclusion
This study reviewed 39 references related to ‘3DCE’ term, including ‘3-DCE’, ‘3D-CE’, ‘three-dimensional concurrent engineering’, and ‘product process supply chain’. The references were collected using the Scopus search engine and PoP software. After the refinement search, we merged both results from the Scopus search engine and PoP software into 39 references. A manual check on all references was conducted to ensure each reference correlated to the 3DCE field.

The benefits of this study are expressed as follows. First, we would recommend reading our 39 references for researchers in the 3DCE field. Second, we would like to propose 3DCE is the formal acronym for three-dimensional concurrent engineering (see Figure 2). Third, we highly recommend using the keywords ‘product development’, ‘product design’, and ‘supply chain’ together with 3DCE in searching for the 3DCE references.

There are at least two limitations of this study. First, it was only used the Scopus database. Second, the keyword 3DCE represented by several keywords and could lead to a miss calculation of occurrences and total link strength. Finally, we strongly suggest to do bibliometric analysis using other database and add more keywords for searching the references.

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