Concurrent Engineering (CE): A Review Literature Report

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Abstract **- This report is a review of work published in various journals on the topics of Concurrent Engineering (CE) between 2000 and 28th July, 2010. A total of 80 articles from 28 journals, eight (8) Conference Proceedings and two (2) books were reviewed. This report intends to serve two goals. First, it will be useful to researchers who are interested in understanding and following the recent trends in the area of CE. Finally, this report will be useful to businesses or industries; because it seeks to highlight the current engineering unanswered but justified research and development (R&D) questions raised in research papers for research and/or development needs. The report is summarized to identify key references in the form of a literature review; thus, identifying key journals and other key forums such as conferences and societies as well as some books in the field of CE. The summary will also identify most cited authors by using a sample statistical report from Harzing's Publish or Perish software. This report will also seek to address the issues and trends, including future perspectives of CE and the CE Product Life Cycle (PLC).**

Index Terms **- Concurrent Engineering (CE); CE Product Life Cycle; CE Trends and Perspective; Journal Articles Survey.**

I. INTRODUCTION

Over the past decade industries in almost all markets have been facing a boosting level of competitiveness. There are many reasons for this, but most of them can be followed to some principal trends: shortening product life cycles, globalization of the market, rapid technological changes, environmental issues, and higher complexity of products, customers demanding products with more features, higher quality, lower cost, and demand for more and more customized products. Concurrent Engineering is an integrated product development approach, CE emphasises the response to customer expectations by producing better, cost effective and much faster products. It also supports multidisciplinary team values of co-operation and trust; thus, sharing and exchanging required knowledge and information in a manner that will enhance decision making processes and also emphasis on simultaneous consideration during the design stage and all the other Product Life Cycle (PLC) aspects of the product development.

One of the most salient means to reduce development time is through the use of "concurrent engineering." Concurrent engineering is defined by the Institute for Defence Analysis (IDA) as: "the systematic approach to the integrated concurrent design of products and related processes, including manufacture and support. Thus, PLC management confronts the need to balance fast response to changing consumer demands with competitive pressure to seek cost reductions in sourcing, manufacturing and distribution. It needs to be based on a close alignment between customer-facing functions (e.g. marketing, sales, customer service) and supply functions (e.g. purchasing, manufacturing, logistics) ([20]; [21]; [50]). Hence, Product life cycle (PLC) management as the integrated, information-driven approach to all aspects of a product's life, from concept to design, manufacturing, maintenance and removal from the market, has become a strategic priority in many company's boardrooms [67].

According to [77]; Concurrent engineering (CE) is an engineering management philosophy and a set of operating principles that guide a product development process through to an accelerated successful completion. In general CE values relay on a single, but powerful, principle that encourages the incorporation the later stages of production concerns into the upstream phases of a development process. This would lead to shorter development times, improved product quality, and lower development–production costs. Concurrent engineering is hereby aimed at the timely availability of critical design information to all development participants. For most intricate engineering tasks all significant information required by a specific development team cannot be completely available at the start of that task.

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Therefore, CE requires the most of such information and the ability to share and communicate useful information on a timely basis with right experts. The concept of concurrent engineering (CE) has been known for quite a while now, and it has been widely recognized as a major enabler of fast and efficient product development. This paper examines the extent to which CE best practices, as obtained from a broad literature review, are being used effectively in companies. Companies both in Belgium and in Italy were investigated using a CE compliance checklist. The paper comments on usage patterns in both countries and compares them. Specific information per sector is also included. Finally, the positive impact of formal CE programs is proven by the data [54].

This report is summarized to identify key references in the form of a literature review; thus, identifying key journals and other key forums such as conferences and societies in the field of Concurrent Engineering (CE) between 2000 and 28th July, 2010 from a total of 80 articles and 28 journals, 8 Conference Proceedings and 2 books. This report intends to serve two goals. First, it will be useful to researchers who are interested in understanding and following the recent trends in the area of CE. Finally, this report will be useful businesses or industries; because it seeks to highlight the current unanswered but justified research and development (R&D) questions raised in research papers for research and/or development needs. The summary will also identify most cited authors by using a sample statistical report from Harzing's Publish or Perish software. This report is divided into eight (8) main sections, including; this introduction, methodology, CE product life cycle (PLC), CE trend and perspectives, review of journal articles, analysis, conclusion and finally research gaps, findings and contribution for future research.

A. Types CE Multidisciplinary Teams

The CE applications depend on having a very well defined multidisciplinary team that is directed by the project leader or CE team leader. The vital CE team members consist of various departments such as: marketing, product engineering, manufacturing engineering, production engineering, finance, quality, logistic control, systems engineering, services and external consultancy or support teams as well as the customers and brokers [3]. Some of the CE multidisciplinary team structures include:

- *Functional Team:* This type of multidisciplinary team very much relates to the orthodox over the wall way of communication where each engineer works in his/her own functional department. This team type should be avoided.
- *Lightweight Team:* This type of multidisciplinary CE team is mainly formed with members from the same department. This CE team type is related to part of the complete PLC.
- *Heavyweight Team:* This type of multidisciplinary CE team is a classical cross-functional CE team. With this type of CE team, members work part-time aside their original departmental duties.
- *Autonomy Team:* This type of multidisciplinary CE team is also a classical cross-functional team where members work full-time from their own offices and also used the departmental resources. With this type of CE team, regular meetings take place among the CE team members.
- *Collocated Autonomy Team:* This type of multidisciplinary CE is much like the autonomy team type of CE, just that, to enhance total dedication to the project as well as the integration of the team, members are brought together in the same working environment with the requisite resources to carry on their activities.
- *The Virtual Team:* This type of multidisciplinary CE team is a geographically distributed, thus, employing information technologies (i.e. internet/intranet, as well as telephone conferences and videoconferences) for communication among members.

TABLE I
HARZING'S PUBLISH OR PERISH MOST CITED CONCURRENT ENGINEERING JOURNAL ARTICLES AND AUTHORS*

Harzing's Publish or Perish - General Citation Search for "Concurrent Engineering (2000-2010)Title words only.					
Cites	**Authors**	**Title**	**Year**	**Source**	**Publisher**
66	[77]	Complex CE and the design structure matrix method	2003	Concurrent Engineering	cer.sagepub.com
32	[58]	Analysis of cost estimating processes used within a CE environment throughout a product life cycle	2000	Advances in Concurrent Engineering: Ce2000	books.google.com
26	[77x]	Four complex problems in CE and the design structure matrix method	2003	Concurrent Engineering Research & Applications	
20	[17]	Design and Implementation: A project task coordination model for team organization in CE	2007	Concurrent Engineering	cer.sagepub.com
16	[2]	CE within British industry	2000	Concurrent Engineering	cer.sagepub.com
15	[38]	Concurrent resource allocation (CRA): A heuristic for multi-project scheduling with resource constraints in CE	2001	Concurrent Engineering	cer.sagepub.com
14	[46]	CE and design oscillations in complex engineering projects	2003	Concurrent Engineering	cer.sagepub.com
14	[25]	Decision support in concurrent engineering-The utility-based selection decision support problem	2005	… Engineering	cer.sagepub.com
9	[53]	Computer based initiatives for implementing and sustaining CE	2002	Concurrent Engineering	cer.sagepub.com
8	[60]	Federated P2P Services in Concurrent Engineering Environments	2002	Concurrent Engineering 2002 Conference.(forthcoming	
8	[6]	Integrating CE concepts in a steelwork construction project	2000	CONCURRENT …	lboro.ac.uk
7	[62]	Managing concurrent engineering design processes and associated knowledge	2006	… engineering: next …	books.google.com
5	[51]	A fractal approach for CE	2003	Int. J. of CE: Research	
5	[74]	Integrated enterprise concurrent engineering: a framework and implementation	2001	Concurrent Engineering	cer.sagepub.com
4	[28]	Taxonomy of information and capitalisation in a Concurrent Engineering context	2000	international conference on concurrent engineering	
4	[80]	Study on process reengineering and integrated enabling tools of CE	2002	International Conference on CE,	
4	[52]	Concept and Model for a Concurrent Engineering Consulting Software System	2000	Concurrent Engineering …	Citeseer

*Harzing's Publish or Perish Most Cited Authors (Accessed on 28/07/2010). *The Harzing's Publish or Perish software used for general citation search for "Concurrent Engineering" in All of the words field, "Concurrent Engineering" in Any of the words field, "Concurrent Engineering" in The Phrase field and then Title words only box ticked setting the dates between (2000- 2010).

II. METHODOLOGY

It is rather hard to confine the report on Concurrent Engineering (CE) to specific orders; the relevant material is spread out across various journals. The criteria for choosing journal articles for the review are as follows. First of all, the article must have been published in a peer-review and/or archival journal. Secondly, to avoid never ending revision of the report, 28th July, 2010 was selected as the cut-off date. Finally, only the articles with 'Concurrent Engineering' as a part of their title contents were selected. The exceptions are those articles that are explicitly dealing with 'Concurrent Engineering' but for some reasons the authors decided not to use 'Concurrent Engineering' in the title. The inclusions of such articles are inevitably unplanned. Consequently, it is possible that there exist more of such articles, which are not surveyed in this report. No restrictions were imposed on the field of the surveyed journals. This should allow a comprehensive set of perspectives on Concurrent Engineering by different fields. According to these criteria, a vigorous attempt has been made to collate all the available journal articles. The effort to compile has been carried out through exhaustive computer search, database search, internet search, reference checking, most cited authors using Harzing's Publish or Perish software, *etc*. However, it is always possible that some of the articles are missing from this list. A Harzing's Publish or Perish software statistical results for mostly cited authors in the field of Concurrent Engineering between 2005 and 2010 is found in Table I above in a descending order:

III. CE PRODUCT LIFE-CYCLE (PLC)

Every product or service has a certain life cycle. Product life-cycle (PLC) is the integrated, information-driven approach to all aspects of a product's life, from concept to design, manufacturing, maintenance and removal from the market, has become a strategic priority in many company's boardrooms [67]. The life cycle refers to the time from the product's first launch into the market until its final withdrawal, and it is split up in phases. During this time significant changes are made in the way that the product is behaving into the market, i.e. its reflection in respect of sales to the company that introduced it into the market. Since an increase in profits is the major goal of a company that introduces a product into a market, the product's life cycle management is very important. Certain companies use strategic planning and others follow the basic rules of the different life cycle phase. The understanding of a product's life cycle can help an industry to understand and realize when it is the time to market or withdraw a product from a market, its position in the market compared to competitors, and the product's success or failure feasibility. For a company to fully understand the above and successfully manage a product's life cycle, needs to develop strategies and methodologies [44].

Industries should manage their products carefully over time to ensure that they deliver products that continue to meet customer needs. In this way industrial organizations maintain a cash flow that covers the company's costs and delivers s a profit to it. Without this profit very few industries can survive in the longer term. The process of managing groups of brands and product lines is called group planning. The life of a product is the period over which it appeals to customers. The sales performance of any product rises from nothing when the product is introduced to the market reaches a peak and then declines to nothing again.

The classic product life cycle has five stages:

- Development
- Growth
- Maturity
- Decline and
- Withdrawal

The Product Life Cycle of some products may last for hundreds of years while for others it may be a few months. If a firm wants to prolong the life cycle of its own distinct product it is essential to invest well in the development of the product and the promotion of it. This may mean that a lot of work is put into the product before it's launched. Once the product is on the market it may be necessary to periodically inject new life into it. This can be done in several ways, including:

- Product improvement
- Extending the product range
- Improved promotion etc.

The Product Life Cycle process is the mechanism through which products are managed from inception to retirement. The Product Life Cycle does not have to end. It can easily be prolonged by a range of marketing and production innovations.

A. Development Stage

At the development Stage market size and growth is slim. It is possible that substantial research and development costs have been incurred in getting the product to this stage. In addition, marketing costs may be high in order to test the market, undergo commencement promotion and set up distribution outlets. It is highly unlikely that industries will make profits on products at the development Stage. Products at this stage have to be carefully monitored to ensure that they start to grow and pick in the market. Otherwise, the best option may be to withdraw or end the product. The need for immediate profit is not a pressure as the lack of it is expected at this time. The product is promoted to create awareness of the market. If the product has no or few competitors, a skimming price strategy is employed to maximise profits. Limited numbers of product will be available in few outlets of distribution. The development stage encompasses a number of activities that will include:

- *Concept:* Overview of the customer requirement that an opportunity seeks to address, supported by evidence of market need.
- *Definition:* High-level definition of customer requirements and analysis of a business opportunity.
- *Design:* Analysis of customer requirements creating project plan and detailed product specification.
- *Development:* Data and software (CAD/CAM) development.
- *Development Testing:* Testing of the product against pre-defined test schedules to ensure satisfactory performance against customer requirements.
- *Development of pricing.*

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- *Development of user guide,*
- *Introduction of the product* to the market (Time to Market). etc.

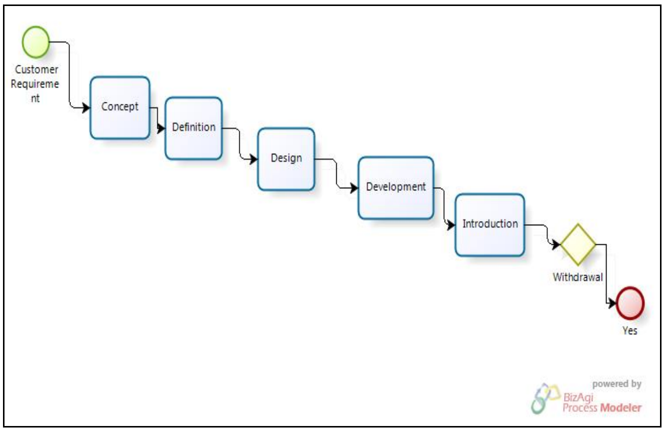

Fig. 1. Introduction Stage (Input and Deliverables) - *Product Life Cycle (PLC)* - Input and Deliverables (BizAgi Process Modeller).

It is in this stage that Engineering Design team comes to the fore and has its major contribution. The intention is ensure that the new product:

- Meets all the customer requirements
- The design time is very much reduced as this leads to
- Shorter time to market for the product
- Shorter time to profitability for the new product
- Increase Return On Investment (ROI)
- Earlier payback of investment costs

B. *Concurrent engineering workflow*

Concurrent engineering (CE) is a workflow that, instead of working chronologically through stages, carries out a number of tasks in parallel. For example: starting tool design before the detailed designs of the product are finished, or starting on detail design solid models before the concept design surface models are complete. Although this does not necessarily reduce the amount of manpower required for a project, it does drastically reduce lead times and thus time to market. Feature-based CAD systems have for many years allowed the simultaneous work on 3D solid model and the 2D drawing by means of two separate files, with the drawing looking at the data in the model; when the model changes the drawing will accordingly update. Some CAD packages also allow associative copying of geometry between files. This allows, for example, the copying of a part design into the files used by the tooling designer. The manufacturing engineer can then start work on tools before the final design freeze; when a design changes size or shapes the tool geometry will then update. Concurrent engineering also has the added benefit of providing better and more immediate communication between departments, reducing the chance of costly, late design changes. It adopts a problem prevention method as compared to the problem solving and re-designing method of traditional sequential engineering.

C. *Design in context*

Individual components cannot be constructed in isolation. Computer aided design - CAD; computer aided industrial design - CAiD models of components are designed within the context of part or the entire product being developed. This is achieved using assembly modelling techniques. Other components' geometry can be seen and referenced within the CAD tool being used. The other components within the sub-assembly may or may not have been constructed in the same system, their geometry being translated from other collaborative product developments - CPD or computer aided manufacture CAM formats. Some assembly checking such as digital mock-up - DMU is also carried out using Product visualization software.

D. *Growth Stage*

The Growth Stage consists of rapid growth in sales and profits as the product or service is becoming established. Profits arise due to an increase in output (economies of scale) and possibly better prices for raw materials and manufactured components. There may be fewer competitors, sales are growing and profit margins are good. Now' is the time to work out how you can reduce the costs of delivering the new product. At this stage, it is cheaper for organizational industries to invest in increasing their business market share as well as enjoying the overall growth of the market. Accordingly, significant promotional resources are usually invested in products that are firmly in the Growth Stage. Competitors are attracted into the market with very similar offerings. Products become more profitable and companies form alliances, joint ventures and take over each other. Hence cost on advertising seems high and focuses upon building brand while market share tends to stabilize in this respect.

E. *Maturity Stage*

The Maturity Stage is, perhaps, the most common stage for all markets. It is at this stage that competition is most intense as companies fight to maintain their market share. Here, both marketing and finance become key activities. Marketing spent has to be monitored carefully, since any significant moves are likely to be copied by competitors. The Maturity Stage is the time when most profit is earned by the market as a whole. Any expenditure on research and development is likely to be restricted to product modification and improvement and perhaps to improve production efficiency and quality. Sales growth will slow or even stopped at this stage. Production and marketing costs may have been reduced, but increased competition would drive down prices. Hence, this moment is likely the best time to invest in a new product introduction or development. Those products that survive the earlier stages tend to spend longest in this phase. Sales grow at a decreasing rate and then stabilize. Producers attempt to differentiate products and brands, which are very essential to this. Price wars and intense competition occur. At this point, the market reaches saturation. Producers begin to leave the market due to poor margins.

F. *Decline Stage*

Decline Stage, denotes that the market is shrinking, reducing the overall amount of profit that can be shared among the remaining competitors. At this stage, great care has to be taken to manage the product carefully. It may be possible to take out some production cost, to transfer production to a cheaper facility, sell the product into other, cheaper markets, etc. Care should also be taken to control the amount of stocks of the product. Ultimately, depending on whether the product remains profitable, a company may decide to end the product. At this point, forward there is a downturn in the market. For example, more innovative products are introduced or consumer tastes have changed. There is intense price-cutting and many more products are withdrawn from the market. Profits can be improved by reducing marketing spend and cost cutting.

G. *Withdrawal stage*

In this stage product retirement takes place and a migration plan for the company products and markets will be established to support customers and partners. It is within this stage of the product life cycle that the recycling and final disposals of constituent components have to be addressed. It is of prime importance that this stage of the Product Life Cycle has to be fully considered during the product development stage. The Fig. 1, above illustrates the process involved in the Product Life Cycle.

H. *Issues with Product Life Cycle (PLC)*

In reality, very few products follow such a prescriptive cycle. The length of each stage varies enormously. The decisions of marketers can change the stage, for example, from maturity to decline by price-cutting. Not all products go through each stage. Some go from the introduction to decline. It is not easy to tell which stage the product is in. Remember that Product life Cycle is like all other tools. Use it to inform your gut feeling. The Product Life Cycle with profit and loss was shown previously in the graphs and has two lines - one to show the level of profit, and other to show the level of sales. Industries will often try to use extension strategies to try to delay the decline stage of the product life cycle. The maturity stage is a good stage for the company in terms of generating cash. The costs of developing the product and establishing it in the market are paid, and it tends to then be at a profitable stage. The longer the company can extend this stage the better it will be for them.

New products and services are the lifeblood of all industrial and organizational businesses. Investing in their development isn't an optional extra - it is crucial to business growth and profitability. However, embarking on the development process is risky. It needs considerable planning and organisation. Identifying where products or services are in their life cycle is central to business profitability. Effective research into industrial markets and competitors will help to do this. Industries can extend the life-cycle of a product or service by investing in an "extension strategy" by:

- Increases to promotional spend.
- Introduce minor innovations - perhaps by adding extra features or updating the design
- Seek new markets

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Even so, ultimately this only delays a product or service's decline. Ideally, industries should always have new products or services to introduce as others decline so that at least one part of the range is showing a sales peak.

IV. CE Trends and Perspectives

According to Tennant, C., and Roberts, P., (2000), an effective New Product Introduction (NPI) process, which is concurrent, can enhance an organisation's competitiveness by compressing product development lead-times, and enabling upstream and downstream processes to be considered when taking decisions at the product concept phase. The application of Concurrent Engineering (CE) (or Integrated Product Development [IPD]) is gradually becoming the norm for developing and introducing new products to the market place [2]. However, the degree to which companies have implemented it and the amount of success varies ([2]; [9]). Many of the companies competing today in international markets consider new product development (NPD) as an important factor for achieving sustainable competitive advantages. Both researchers and managers are constantly searching for methods and practices that will allow them to improve the organization and management of their NPD processes and boost their effectiveness or success the average success rate of NPD projects today is approximately 60% [22]. The test; is to achieve distinction in three specific objectives: (1) shorter new product development times, (2) more efficient developments, and (3) superior products.

On the above note, manufacturing companies have re-systematized their NPD processes and have moved from a sequential path, in which there is a negligible interaction among the departments involved and the activities required to develop the product which is carried out sequentially, towards an integrated path, known as concurrent engineering (CE), in which the activities overlap and all the departments collaborate from the beginning. This new organizational design has helped companies improve their performance by leading to lower costs, higher quality, major knowledge creation and shorter product development times ([10]; [70]), all of which, in turn, has raised their competitive skills. Hence, the aim is to avoid continuous setbacks and the other problems that arise with the traditional approach, improving NPD performance. This new practice, named CE, tries to speed up the process, increasing flexibility, adopting a more strategic perspective with more sensitivity to change in the environment, solving problems through teamwork, developing diverse skills, and improving internal communication [10]. To achieve the above-mentioned objectives, CE is based on three basic elements [42]:

(1) Concurrent work-flow,
(2) Early involvement of all participants and groups contributing to product development, and
(3) Team work. In other words, CE is the early involvement of a cross-functional team to simultaneously plan product, process and manufacturing activities and mentioned earlier in the previous paragraphs.

Many studies demonstrate that CE can successfully solve the typical problems of traditional NPD, leading to clear improvements in quality and marked reductions in development time and costs ([13]; [35]; [10]; [42]). On the other hand, further recent research also has also revealed that, the use of CE on its own does not always lead to positive results and that success in improving innovation capabilities depends on the context, in which CE is applied, that is, on the prevailing competitive and technological circumstances, [71]. Therefore, a conclusion is reached that the scale of vagueness and intricacy present in the process of innovation may moderate the effectiveness of concurrent NPD characteristics on performance. Therefore, the matter to be considered is not, whether CE is a mechanism for improving performance in the introduction of new products but, rather, under what circumstances such as improvement can be accomplished. It seems. However, that, in spite of many research efforts, in studying this aspect, a consensus is yet been reached and that there are many empirical disagreements. This lack of agreement is the reason for this part of the review study on the trends and perspective of CE, the main aim of which is to help determine the trends and perspective circumstances under which the application of CE is successful, effective and more efficient.

According to [14], industrial manufacturing company endeavor to create an advanced core system analytical solution integration process across their industrial manufacturing processes. Thus, this will enhance the efforts by industrial processes by reducing lead-time variability and minimizing the transition times to achieve performance consistency. This kind of system integrated product design and manufacturing collaboration; service-oriented architecture (SOA) turns out to be the most preferred systems' application platform suitable for the recommended Enterprise Service Architecture for this integration process. Further to this analytical leverage of CE system applications and processes; this collaboration has also been accordingly confirmed in [71] research on 'Concurrent engineering performance: Incremental versus radical innovation': Which has revealed that, the use of CE on its own does not always lead to positive results and that success in improving innovation capabilities depends on the context, in which CE is applied, that is, on the prevailing competitive and technological circumstances? [27], the extensive applications of computer aided engineering (CAE) technologies are necessary so that the maximum design efficiency and effectiveness can be accomplished prior to initial sample production. The main characteristic of such an approach is depended largely on the system integration in accordance with the design process.

V. Review of The Journal Articles

In this section, is a brief aggregate summary of the journal articles used in this report is provided in the following tables below. It is not intended to provide a detail description of each article and references of major topics and sub topics used in this review report. Hence, an attempt to draw a collective summary report is made in this section.

TABLE II
NUMBER OF ARTICLES IN EACH JOURNAL (ALL IN ALPHABETICAL ORDER)

Journals	Number of CE Journal Articles
Academic Press	6
Annals of the CIRP	1
Citeseer	2
Computers in Industry	3
CRC	6
IEEE Transactions on Engineering Management	1
Industrial Management	1
Industry Week	1
Integrated Manufacturing Systems	1
International Journal of Concurrent Engineering	2
International Journal of Manufacturing Technology and Management	1
International Journal of Production Economics	4
International Journal of Production Research	3
International Journal of Project Management	3
International Journal of Technology Management	1
Journal of Engineering Manufacture	1
Journal of Engineering Technology Management	1
Journal of Knowledge Management	1
Journal of Management Development	1
Journal of Materials Processing Technology	1
Journal of Operations Management	3
Journal of Product Innovation Management	2
Management Science	1
R&D Management	1
Robotics and Computer Integrated Manufacturing	2
Sage Journal Publications	25
Springer Publications	4
Supply Chain Management Review	2
Total	**80**

Analysis of Journal articles used in this review report

TABLE III
CONFERENCE AND SOCIETY PROCEEDING ARTICLES

Conferences and Society's Proceeding Articles			
Main Event	**Topic**	**Coordinators**	**Year**
Concurrent Engineering Research Group. International Conference of CE (CE 99), Bath-England.	Concurrent Engineering Framework: A Mexican Perspective	[3]	2000
Product Development Institute Inc. Ancaster, Ontario, Canada.	Best Practices in Product Innovation: What Distinguishes Top Performers	[22]	2003
Urban & Regional Innovation Research Unit, Faculty of Engineer. Aristotle University of Thessaloniki.	Product Life Cycle Management	[44].	2002
International Conference on Concurrent Engineering	Study on process reengineering and integrated enabling tools of CE	[80]	2002
International conference on concurrent engineering.	Taxonomy of information and capitalisation in a Concurrent Engineering context	[28]	2000
Concurrent Engineering Conference.(forthcoming …	Federated P2P Services in Concurrent Engineering Environments	[60]	2002
European Commission, BRITE, EURAM and Fundamental Research, Project No.7094.	'Manufacturing Strategic Decision Support Tools: Linking Corporate Vision to Measures of Manufacturing Performance in CE	[59]	2005
Proceeding of the 2006 conference on Leading the Web in CE, IOS Press Amsterdam, The Netherlands, Vol. 143, pp. 325-334.	Considering KMS Implementation in Concurrent Engineering-economic perspective	[79]	2002
Book(s) Used			
Publisher	**Topic**	**Author**	**Year**
Wiley Publishing, Inc. 10475 Crosspoint Boulevard, Indianapolis, IN 46256.	Mastering Enterprise SOA with SAP Netweaver and mySAP ERP	[14]	2007
CIM Press, P. O. Box 100, Cambria, California 93428-0100.	Design For Manufacture and Concurrent Engineering	[5]	2008

Conferences and Society's Proceeding Articles Used in this Review Report & Book(s)

Table IV shows main topics and major research areas used in the journal article includes in this review report. A comprehensive table containing main topic areas and their classified references for each topic is provided in Table IV below. There is no particular sequence among the references listed in the table. It is unavoidable to have an article that is relevant to more than one topic. For example, an article may address implementation issues but provide general information or extension/trends and perspective on CE. In such a case, more credence topics are chosen to classify the article according to the reporter's judgment. Listing an article under more than one topic was hereby allowed.

I. *CE Implementation*

The effective New Product Introduction (NPI) process, which is concurrent, can enhance an organisation's competitiveness by compressing product development lead-times, and enabling upstream and downstream processes to be considered when taking decisions at the product concept phase [66]. This approach is typically described as Concurrent Engineering (CE). Hence, CE in an organization signifies the ability of the organization to embrace product development as a series of overlapping stages, which provides customer satisfaction and also the right price by delivering products on time. This effectively accomplished by employing numerous engineering tools and system techniques during the project management of design product development.

TABLE IV
TOPICS AND REFERENCES

Topic	References
Implementation	[27]; [77]; [16]; [2]; [15]; [38]; [25]; [75]; [6]; [18]; [62]; [74]; [19]; [23]; [22]; [51]; [80]; [64]; [40]; [17]; [30]; [39]; [41]; [8]; [29]; [43]; [48]; [49]; [73]; [65]; [63]; [79]; [70]; [59]; [1]; [9]; [10]; [20];
CE Uses / Value	[58]; [31]; [28]; [7]; [11]; [32]; [68]; [69]; [73]; [76]; [8]; [59]; [55]; [72]; [28]; [79]; [2]
Extension /Trends and Perspectives	[7]; [77]; [46]; [12]; [53]; [60]; [15]; [33]; [36]; [78]; [40]; [45]; [57]; [63]; [24]; [61]; [68]; [69]; [26]; [79]; [47]; [4]; [34]; [3]; [8]

Analysis of references: major topics used in this review report

J. *CE Uses / Values*

Some of the most notable values and uses of concurrent engineering in recent times are to achieve excellence among other organizational objectives, including: shorter new product development times, more efficiency in development activities or system techniques and superior products with the estimated design time frame. On this note, industries have reorganized their new product introduction and development (NPI/D) processes and have subsequently moved from a sequential path, which means minimal communication among the concurrent departments involved and the subsequent activities required in developing a new product. Thus, all the departments collaborate from the beginning, by carrying out the product development sequentially towards an integrated path known as concurrent engineering (CE). With this approach, the activities overlap and hence, all the departments involved collaborating from the beginning. This new organizational design approach has helped industries to improve their performance by leading to lower cost, higher quality, major knowledge creation and shorter product development times ([10]; [70]) all of which increases the organizational competitive skills.

K. *CE Extension/Trends and Perspective*

According to [56], Information and communication technologies (ICT) have altered the balance of cost between activities within a firm and activities between firms. Easier co-operation allows companies to focus on their core strengths, while forming relations with other firms to supply the other needed skills to bring a product to market. Design, in one firm or in a consortium, is iterative and does require a change. The ability of companies to better manage engineering changes (ECs) during product development can decrease cost, shorten development time, and produce higher quality products. Although organisational aspects of change management have received much attention, relatively little research has addressed engineering change (EC) support in manufacturing companies related to product development [37]. Industrial manufacturing company endeavor to create an advanced core system analytical solution integration process across their industrial manufacturing processes, [14]. This will therefore, enhance industrial efforts and processes by reducing lead-time variability and also reduce the transition times to achieve performance consistency. [64], proposed a new information technology platform based on software collaborative services supporting different CE processes, which would be among the first of its kind to attempt to apply collaborative reference architecture to support CE in manufacturing industries. According to [71], service-oriented architecture (SOA) seems to be a most suitable system application platform for the integration and collaboration of engineering product design and development. Thus, the extensive applications of computer aided engineering (CAE) technologies are essential to enhancing the maximum engineering design efficiency and effectiveness [27].

VI. Analysis

CE has seen some relatively drastic decline over a decade. Fig. 2. below and the data table beside it, shows the number of journal articles published from 2000, which has somehow seen some drastic decline fluctuation in the trend over time. The significant declines over these recent years are clearly plotted in Fig. 2. below. Earlier journal articles in the field of CE started appearing in the late 1980s, early 1990s through the 2000s where it gained significant research interests from many industrial organizations and researchers in a short period of time between the 1990s through the early 2000s. From the analysis deduced from the Tables III and IV above: CE implementation and related journal articles surveyed are about 47.5%; journal articles surveyed on CE uses and/or values formed about 21.3% and finally CE extension/trends and perspective and related journal articles formed 31.3% of the journal articles surveyed.

Year	**# CE JA**
2000	17
2001	18
2002	9
2003	7
2004	2
2005	7
2006	13
2007	6
2008	0
2009	1
2010	0
Total JA	**80**

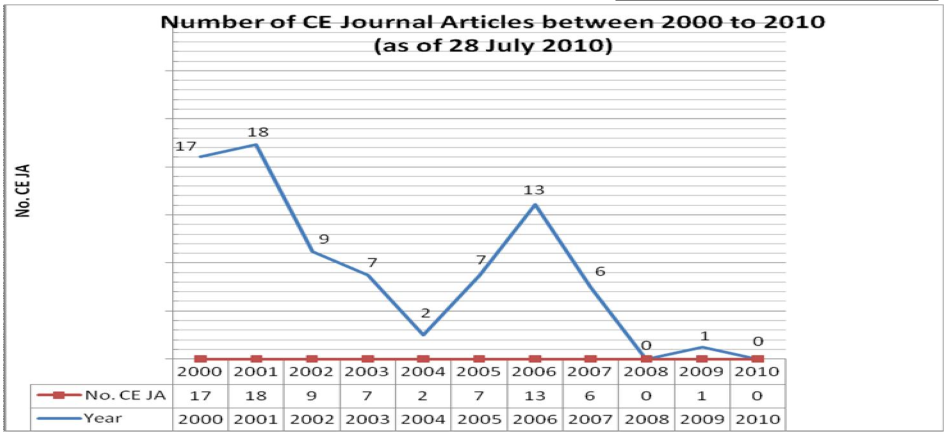

Fig. 2. Number of journal articles on CE between: 2000–2010 (as of 28 July 2010) - (Harzing's Publish or Perish sofware search results[runned on 28/07/2010] statistical chart & table.

From the data in Table IV above from which the statistical data in Table V is deduced; a conclusive analysis could be drawn on the fact that the number of journal articles published on the topics such as CE Uses and/or Values and CE Extension / Trends and Perspective are areas, which are lacking in CE research and development, which can be verified in Tables IV and V above. From the data deduced as well as the findings from this report's analysis in Tables IV and V above: Percentage analysis on CE Uses/Values constitutes 21.3% as well as CE Extension/Trends and Perspective, which are also 31.3%. These are the two averagely under researched and developed areas according to the findings in this review report, which requires further research and development to enhance competitiveness in industrial organizations.

TABLE V
NUMBER OF PUBLISHED ARTICLES FOR EACH TOPIC

Topics	**Number of Articles**	**% of No. Of JA Surveyed**
Implementation	38	47.5%
CE Uses / Values	17	21.3%
Extension / Trends and perspectives	25	31.3%

A table of Number of Published Articles for each of the CE major topic areas.

VII. Conclusion

CE approach as an industrial manufacturing organization's competitive methodology or 'best practice' way of working, in a way, CE seems to be maturing from its original or orthodox methodology into some kind of extension, that is, by collaboration with some engineering ICT technologies for a better efficient and effective industrial competitiveness. This review report in its CE journal article survey has help to identify some suitable collaborative engineering ICT technology platforms such as SOA to enhance the collaborative effectiveness and efficiencies. This report in its findings also identified that, not much research has been conducted in the area of CE literature review as well as CE uses/values and CE extension/trends and perspectives; in that, over a decade (2000-2010) as reviewed and surveyed by this report its only just over 80 CE journal articles has been researched in the field of CE. Thus, on this note, it might be a time for industrial manufacturing organizations and scholars or the academia to reflect on their experiences and begin publishing for common good and also for industrial competitive advantage.

VIII. Research Gaps; Findings and Contributions for Future Research

Analysis and findings, from the above data in Tables IV and V as well as the trend of data analysis in Fig. 2. and its subsequent percentage data analysis; the survey finds were that, not enough research has been conducted in the areas of CE uses/ values as well as CE extension/trends and perspective, hence their percentage scope of research was well below average. Therefore, this review report has identified that there are research gaps in these very essential areas which need to be addressed for the common good and achievement industrial competitiveness as these areas forms part of the key drivers CE maturity in this modern era. Thus, this review report seeks to propose further research into these CE areas with more interest and focus on the area of CE extension/trends and perspective as CE is entering its maturity era in this age or ICT industrial manufacturing efficiency and competitiveness. Collaboration of CE with suitable system application processes in this review report, service-oriented architecture (SOA) seems to be a most suitable system application platform for the integration and collaboration of engineering product design and development, which needs to be further researched to prove its suitability.

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