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Internal and External Involvements in Integrated Product Development: A Two-Step Clustering Approach

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Abstract

The term Integrated Product Development (IPD) has been introduced as a focus for cross-disciplinary research and can have several forms, or manifestations, with regard to the existing disciplines such as concurrent engineering and design for manufacturing. Of central importance to IPD is the interpretation of the term "integration", particularly with regard to internal and external elements. However, there is not yet an explicit understanding of an appropriate degree of integration, or involvement, with respect to its different forms, that can assure successful implementation of IPD frameworks in practice. Through a review and clustering of the literature, this paper aims to address this challenge.

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Keywords: Integrated Product Development; New Product Development; Concurrent Engineering; Design for Manufacturing; Engineering Design; Literature Review; Process Modelling; Clustering Analysis

1. Preliminary

The term Integrated Product Development (IPD) is associated with improvement and management of New Product Development (NPD) processes through standardization. Over the past decades, due to its multi-disciplinary essence, it has been interchangeably used with other manifestations of process improvement and management, such as Concurrent Engineering (CE) and Design for Manufacturing (DFM).

In addition, along with the increase in complexity of NPD processes as well as such advancement in developing more sophisticated methods, tools, and techniques, there have been appeared multiple interpretations of the term "integration" in IPD. This has resulted in the emergence of topics such as Integrated Product-Process Systems, Integrated Product-Service Systems, Integrated Product Teams, Cloud-based Design and Manufacturing and Collaborative and Distributed Design. As a result, depending on the performance objectives, each of these aspects comes with a different combination and degree of involvement of traditional NPD elements (e.g., customer, design, manufacturing, assembly and supplier).

Therefore, an emerging debate in the research community is that of understanding what is the appropriate degree of involvement of modeling in IPD frameworks, with respect to the internal or external elements, that can assure successful implementation of IPD in practice?

The topic is fundamentally important in the context of IPD modeling since, on the one hand, there are many suggestions in the literature to involve the major NPD elements *as early as possible* during design and planning. On the other hand, others argue that these elements should be kept in mind *as much as possible* during design and planning. However, the reality of IPD modeling and implementation reveals that full integration (involvement) is not always achievable in practice due, for example, to the huge amount of mutual and often conflicting dependencies among stakeholders. Hence, there should always be a compromise between degree of involvement of internal or external factors (complexity of an IPD configuration) and the efficiency of its implementation.

The main contribution of this paper is to address the above debate, through reviewing, clustering, and analysis of the relevant literature with the aim to propose a common ground for the configuration of future IPD efforts. Our specific

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objectives are to understand: (1) which are the most relevant publications in the literature with respect to each IPD manifestation; (2) to what extent multiple internal and external involvements of NPD have been addressed in the literature; (3) which are the most influential sources of involvement that should be more prominent; (4) which kind of models in the literature are more appropriate for involving particular elements; and (5) what can be learned from the diversity of previous research in IPD in general.

To satisfy the above objectives, an extensive search of the literature was undertaken to find a sufficient amount of publications pertaining to each IPD manifestation (Section 2). The repository of publications was then reviewed, with attention on involving the internal (related to the product, process, organization, etc.) and external (related to suppliers, customers, partners, competitors, etc.) elements of NPD process and with regard to the different manifestations of IPD (Section 3). Using the functionality of SPSS® software, a two-step procedure was applied to cluster the publications based on their similarity in addressing the same range of NPD elements (Section 4). The paper finally concludes with a discussion of the findings and some remarks for future modeling directions (Section 5).

2. Research methodology

The literature of IPD is dispersed and contributes many facets. As a result, a step-by-step procedure was followed to narrow down the search criteria and collect a sufficient and representative set of publications:

1. A parallel search of Scopus, Engineering Village and Google Scholar with a set of 10 keywords, including Concurrent Engineering, Integrated Product Development, Design for Manufacturing, Product Development, Integrated Design, New Product Development, Integrated Product, Engineering Design, Product-Service Systems and Modern Project Management, within the scope of the past ten years (from early 2006 to the end of 2015). The goal was to find such advancements in modelling IPD.
2. A review of emerging titles and abstracts to determine if the found paper was somehow concerned with any kind of internal or external integration in PDP.
3. On ongoing filtering of a master list against the scope of the paper. In doing so, many papers were eliminated from the list, due to: (1) language of the paper was not in English; (2) it was a conference paper and later matured as a journal paper; (3) it was not possible to get the full-text; and (4) the paper was a duplicate.

Overall, 108 references were found, with a contribution of the order of 2030 citations in total (based on Google Scholar, up to 30 April 2016). The full-texts were downloaded to the Mendeley® platform and used for review and analysis. The composition of the publications is presented in Figure 1. Of the 108 papers, 79 were from journals and the remaining 29 were from conference proceedings.

In comparison to previous reviews (e.g., [1], [2], [3], [4]), the paper has a broader perspective of IPD modeling and covers not only multiple aspects of research in IPD but also its associated disciplines such as CE and DFX. This more comprehensive scope is intended to lead to a better understanding of the transformation of patterns and values over the years and consequently, enables the drawing of a picture of future IPD models.

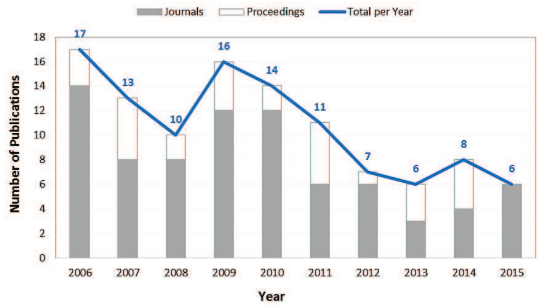

Figure 1. Year-wise distribution of publications based on their type

3. Literature review

The literature of IPD modeling has always been concerned with an ongoing debate around several aspects pertaining to its multiple forms (manifestations), successful implementation and configuration (structure). As far as this is related to the scope of this paper, the references were first classified based on their perspective on the term IPD and then studied based on their richness in addressing internal and external elements of the NPD process.

3.1. Multiple manifestations of IPD

Depending on the characteristics of performance objectives, scope of influencing and degree of involvement (integration), IPD has been viewed from so different ways in the literature and modelled using different sets of methodologies, tools, and techniques, nevertheless all of which have been concerned with as such integrating *as early as possible* and *as much as possible*. Two dominant groups of approaches emerged as the result, namely CE and DFX.

Accordingly, the references were grouped into three research themes: (1) CE, including any models within the domain of concurrent and simultaneous engineering; (2) DFX, including the models that believed the consequent phases of a product lifecycle should proactively be considered early during design, e.g., design for manufacturing and assembly, design for quality -cost, design for sustainability, design for environment, etc.; and (3) Other IPDs, including the models that identified IPD as an independent management style and also approaches that had different interpretations of the term *integration* (see Par.2 in Section 1). The year-wise frequency of these themes is presented in Figure 2.

Attempts were made to collect the samples pertaining to each theme big enough to make the clustering and analysis reasonable and also to cover multiple forms of IPD as much as possible. As a result, from a total of 108 references, 38 were assigned to CE, 33 to DFX and 37 to Other IPDs.

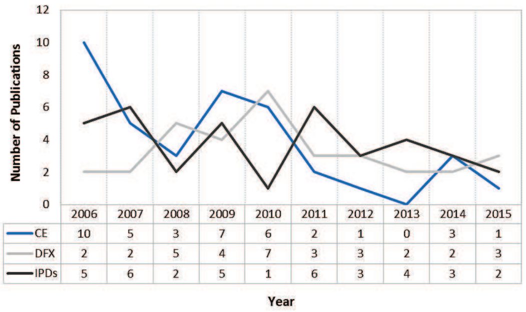

Figure 2. Year-wise distribution of publications based on their theme

3.2. Degree of involvements and evolution of IPD models

In the context of an IPD framework, involvements (integration) can be addressed based on their nature, direction and degree:

- In terms of *nature*, integration can be internal (refers to any aspect of product, process, organization, procedure, structure and management) or external (refers to any aspect of supplier, technology/market, customer, partners, competitors, policy, environment, etc.);
- In terms of *direction*, integration can be upward (to any aspect of management, marketing, customer, finance, etc.) or downward (to any aspect of supplier, design, prototyping, manufacturing, assembly, recycling, maintenance, etc.);
- In terms of *degree*, integration can contain any of the above aspects such as supplier, design, production (including prototyping), manufacturing, assembly (including machining), marketing (including technology), supplier and logistics, maintenance and recycling and customer or partners.

Understanding any of these dimensions can help identify the behavior of models in other dimensions. This led to the generation of a general-view, multi-domain matrix, with the references (grouped by the theme) in the rows and the NPD elements in the columns, as a means to understand the relative richness of IPD models in addressing the elements. The data was then used to cluster and analyze the models.

Given the multiple links from the IPDs identified and the evaluation criteria, the richness of the models was investigated from two perspectives: (a) with respect to the publication date and (b) with respect to the research themes. The former provides insight on the evolution of IPD models over the years, while the latter supports the identification of the most influential elements with regard to each research theme:

(a) Figure 3 shows the normalized average of the richness of models per each research theme (the comparative lines) and the overall normalized richness per year (bar chart). With regard to the themes, the figure shows that CE and DFX are located above the Other IPDs in most cases. In other words, those references were supposed to take more elements of NPD processes into modeling. However, the overall rate of evolution (in the sense of addressing more elements) did not represent a considerable difference, allowing for some fluctuations over the past decade.

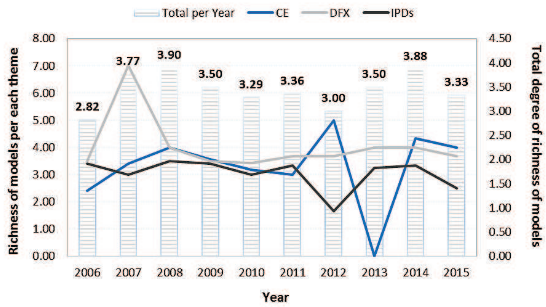

Figure 3. Evolution of IPD models over the past decade

(b) The extent that major NPD elements have been involved in the literature is shown in Figure 4. The percentages imply that an NPD element, for example, planning, has been

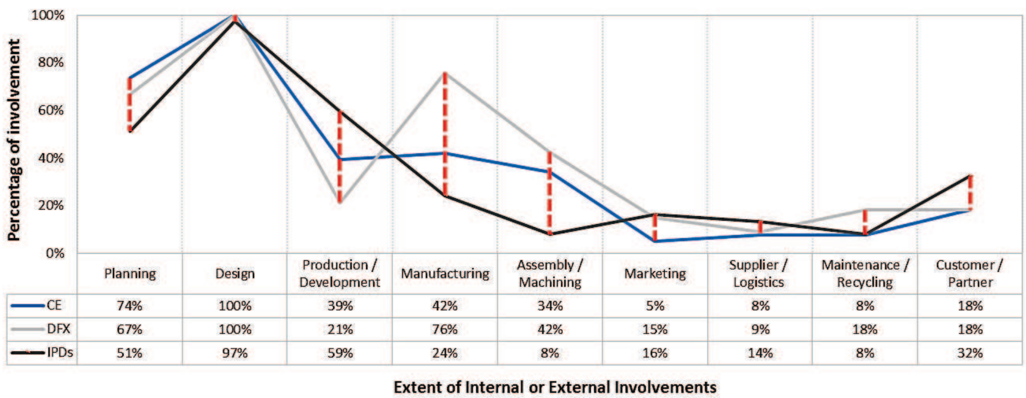

Figure 4. Extent of internal and external involvements in IPD

recognized to be directly addressed in 74% of the CE references (28 out of 38 references). The overall patterns confirmed that design on the one hand and marketing, supplier and logistics and maintenance, on the other, have been respectively the most and least frequently addressed elements in the literature. *The authors argued that planning, production, manufacturing, assembly, and customer in any order might be most influential elements* in the previous modelling attempts, probably due to the existence of a significant difference in the involvements regarding the research themes. Through clustering the literature in the next section, the aim was to enable a more detailed investigation of the interplay between different manifestations of IPD (research themes) and the degree of involvement of NPD elements.

4. Clustering analysis and discussion

For the purpose of cluster analysis, a two-step procedure was used, mainly due to its capability to clustering large amounts of data and to automatically determine the optimal number of clusters. The multi-domain matrix acted as the database (108 references * 9 elements) and was imported into SPSS®. The distance measure was set to Euclidean, the clustering criterion to Schwarz's Bayesian Criterion and the maximum number of clusters bounded to 10.

Figure 5 shows the multi-view result of the cluster analysis. The optimal number of clusters achieved was seven and, in view of this, the parallel bar charts in the figure presented the distribution of references in satisfying each of the elements. Concerning the size of clusters, the figure implies a sensible distribution of publications, with none of the clusters exceeding 20 references. Another aspect of results was the predictor

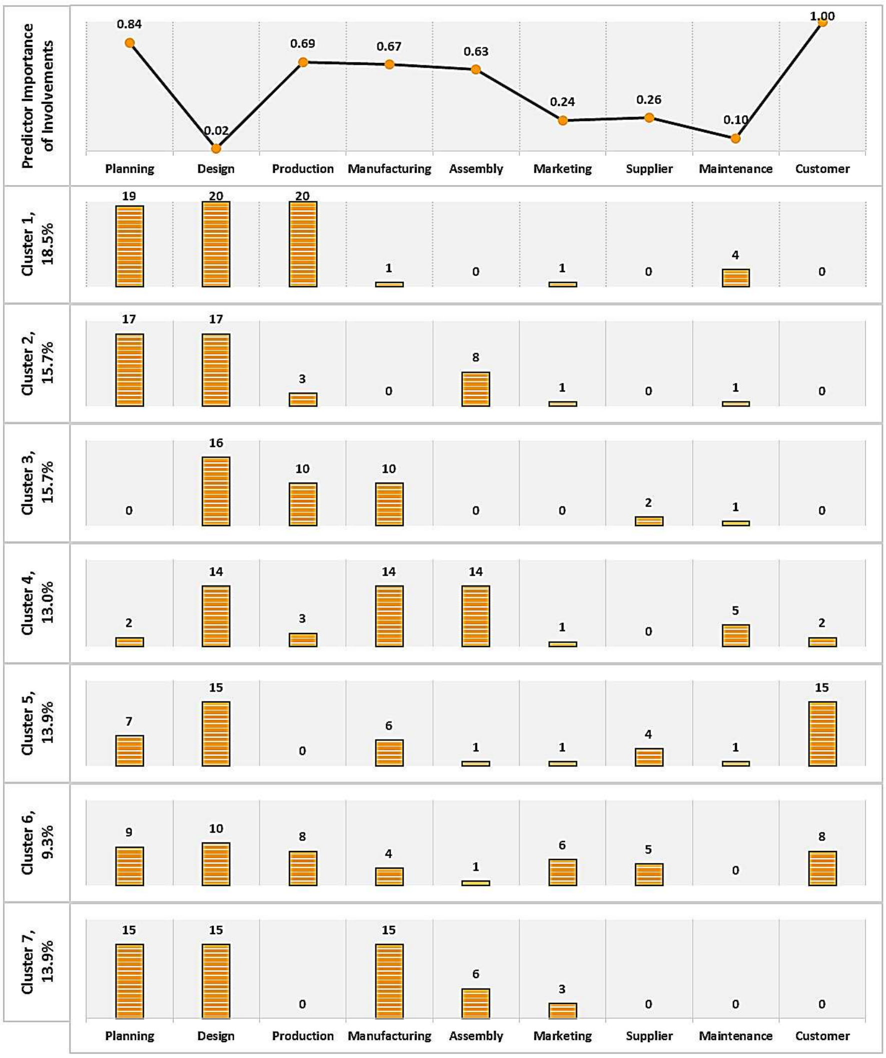

Figure 5. Result of cluster analysis (representing the parallel distribution of data in seven clusters and the predictor importance of NPD elements at the top)

importance chart for the variables (elements) that automatically generated by SPSS®.

At a general level, it was interesting that the predictor importance numbers (line chart at the top of Figure 5) verified previous findings and customer, planning, production, manufacturing and assembly were respectively recognized as the most influential elements (Section 3.2(b)). On the other hand, the most and least frequently addressed elements in the literature (respectively design, maintenance, supplier and logistics and marketing) were found to have the lowest impact on the results.

At a more detail level, by looking at the parallel charts, some dominant elements were found in each cluster. The cluster membership presented in Table 1 includes the overall membership, the membership in each research theme and the dominant elements in each cluster. In general, Figure 5 and Table 1 can be discussed from two perspectives: with respect to the elements and to the research themes.

In the former regard, three different patterns can be observed from the results. The references in clusters 1, 2 and 7 represented a particular attention to relatively few aspects of integration and specifically the early phases of NPD process. For example, in cluster 2, where CE was the dominant theme, there was more attention to the planning, design, and somehow assembly phases, while in cluster 7, where DFX was the dominant theme, it was interesting that all of the publications have been involved the planning and manufacturing phases into the modeling.

Clusters 5 and 6, on the contrary, included the references with greater attention to the external elements of integration (marketing, supplier, and customer), i.e., the models involving the customer were found in these clusters. Though, the references in these groups attempted to have a more integrated perspective on the NPD process, through involving more internal and external elements into the modeling.

The third pattern was observed in clusters 3 and 4 where more focus was placed on the middle phases of NPD processes and especially manufacturing, e.g., all the references in cluster 4 in some way dealt with the manufacturing and assembly phases.

In relation to the associations between the research themes and the clusters, the results show a good distribution of publications in clusters 5 and 6. As mentioned, these are also the only two clusters with more attention on the integration of external elements such as marketing, supplier, and customer. On the other hand, the largest amount of variance was found in clusters 2, 3 and 7, where CE, Other IPDs, and DFX were respectively the dominant themes. Hence, by considering Figure 4, 5 and Table 1, it can be summarized that:

- References in CE and Other IPDs were mainly concerned with early involvements, through consideration of the very early elements of NPD process such as planning, design, and production (see the references in clusters 1, 2 and 6).
- The majority of references in DFX were concerned with the involvement of the manufacturing and assembly phases during design and planning (see the references in clusters 4 and 7).
- The internal elements, such as planning, production, manufacturing and assembly, were recognized to have more influence in making a distinction in the literature of IPD and researchers from different disciplines presented different combinations of their involvement.
- Among the external elements, the role of the customer in designing a new product brought more attention. The rest of marketing (including technology), supplier (including logistics) and maintenance (including recycling and disposal) were the least frequently addressed elements in the literature (see Figure 4) and hence could not have had a strong influence in clustering the references (as regarded in Figure 5 in predictor importance).

5. Conclusive remarks

This paper has addressed a common challenge in modeling IPDs and tried to understand the appropriate degree of integration (or involvement) of NPD elements, with regard to their internal and external nature. To satisfy the research objectives, a general classification of a sample of 108 references was presented, based on their interpretation of the term integration. Subsequently, the extent to which the

Table 1. Cluster membership

Number	Cluster membership	Dominant involvements	CE	DFX	IPDs	Total
Cluster 1	[5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]	Planning, Production	7	3	10	20
Cluster 2	[25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41]	Planning, Assembly	11	3	3	17
Cluster 3	[42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58]	Production, Manufacturing	4	2	11	17
Cluster 4	[59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72]	Manufacturing, Assembly	6	7	1	14
Cluster 5	[73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87]	Customer	5	4	6	15
Cluster 6	[88], [89], [90], [91], [92], [93], [94], [95], [96], [97]	Planning, Production, Customer	2	3	5	10
Cluster 7	[98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112]	Planning, Manufacturing	3	11	1	15

references addressed a range of NPD elements was investigated. The resulting observations were used to cluster the literature in order to understand which types of the model might be better equipped to address different NPD elements?

The results of the clustering verified that complete integration has not been achieved yet and the references in different disciplines come with various combinations of the elements (different degrees of involvement) and at various levels of granularity. DFX were mainly focused on the internal elements and, in particular, manufacturing and assembly phases at a more detailed level of abstraction and by using a broader range of methods, tools, and techniques. Research in CE attempted to improve the process performance by predominately focusing on the early phases of an NPD process, in response to its ability to adapt to the most recent technologies (such as 3D-CAD, integrated FEA and IT). Other aspects of integration (so-called Other IPDs) reflected a better ability to integrate more elements of the NPD into a single platform, albeit at a more abstract level and with a particular interest in improving coordination and communication.

In summary, it is difficult to come up with a dominant and common language (of the formulation) in the context of IPD modeling. However, there is no doubt that both internal and external sources of NPD elements should be considered in an integrated platform (and not side-by-side) so that they are able to support process improvement in either aspect of technical or social systems. This provides an open challenge for the research community to make appropriate tradeoffs between the degree of abstraction and degree of involvement and, at a higher level, to provide a means for IPD frameworks to cover these multiple manifestations.

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