

# The fractal structure for large development programs

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**Abstract:** The organizational structure of Embraer's EMBRAER 170/190 Program has made it possible to integrate the efforts of thousands of people from many different countries and from different companies to the conception, planning, and construction of new regional jets aimed at serving the needs of the market adopting competitive timeframes, competitive prices and competitive performances. This organizational structure comprises a hierarchy of management cells operating within a matrix structure. These management cells provide the structural support for the integrating function of the hierarchy of a large integrated product development program; thereby guaranteeing that the critical technical and management areas are present at the various levels of the project's work breakdown structure. There is a great potential for self-similarity – a defining property of fractals – in the make-up of these cells, and so the metaphor of the fractal structure that we develop here emerges quite naturally.

**Keywords:** innovation management, project organization, cross functional integration, management cells, organizational metaphors.

## 1. Introduction

For a great many years, large companies have been looking for management tools that allow them to innovate by bringing together the competitive advantages they have by virtue of their size with the agility of small companies. This implies keeping specialist areas and, at the same time, a high level of integration between them.

Integrated product development reached a milestone with Don Clausing's book (1994). The central concern of his text consists of the integrative aspect of the process. He examines topics such as the robust project, the incremental definition of the product, team multi-functionality and the global vision of the development process, from customer requirements to the concept and from the concept back to the customer.

Over the last ten years, Integrated Product Development has been increasingly seen as a model for facing up to the challenges posed by integrated management (GERWIN; BARROWMAN, 2002). In a recent review, GERWIN; BARROWMAN (2002) indicate the need for more research that seeks to understand how to coordinate and integrate: "1) the hierarchy of teams in large development projects, because studies focus on the managing team and do not deal with its relationships with the other teams that of necessity exist in any large project; 2) a portfolio of multiple and partially concurrent projects within a company; and 3) the partners in the development effort".

In this paper, our aim is to put together a new descriptive and normative concept and a new metaphor for the

organizational structure (the fractal structure) of a large integrated product development project. This new geometric metaphor (MORGAN, 1996) is based on the fractals property of self-similarity. The fractal metaphor helps when it comes to understanding the integrative function that is necessary for top performance in large projects. The new metaphor we have developed here deals with problems (1) and (3) mentioned above. But in this paper our focus will be on the first issue.

As a practical illustration we shall also examine the organization of the EMBRAER 170/190 Program. It is worth highlighting here that the expression 'fractal structure' is not used by Embraer. This is a concept that we, as authors, are proposing. As will become clear from the text, Embraer sees the 170/190 Program structure as a matrix structure, with the inclusion of management cells to make it easy to integrate the areas and the partners that were necessary to the success of the program. Another paper dealt with the case from this perspective (TROMBONI et al., 2005).

The work continues with a methodological note on how we devised the concept. There follows an abstract discussion on the fractal structure concept and the presentation of Embraer's 170/190 Program. The paper concludes with a discussion, conclusions, limitations and research suggestions, as well as with implications in terms of management practice.

## 2. Discovery and metaphor when constructing a concept

The new metaphor was born out of an intriguing observation. When looking at the diagram of the organizational structure of the EMBRAER 170/190 Program, we were struck

by the unusualness of its design. This episode is illustrative of the four stages of science as Omnés (1994) sees it, namely: a) discovery, or the empirical phase, in which researchers become aware of a new phenomenon; b) conception, or the creation of concepts for describing and dealing with the newly observed phenomenon; c) elaboration, in which successively refined hypotheses are put forward and correlating aspects of the phenomenon and theoretical explanations are considered, tested and discarded in succession; and d) formalization, when the construction of theoretical concepts and the formulation of empirical laws have advanced sufficiently to allow for the construction of refined theoretical and formal structures, with which to explain the reality of the phenomena axiomatically and deductively.

Omnés reminds us that the scientific method is only applicable in the effort to verify the truth of scientific theories; there is no system that can guarantee the discovery or creation of concepts. Morgan (1996) formulates and adopts the metaphor method (in the sense of heuristic rules) as a tool for creating concepts and naming the various ways of looking at and theorizing about organizations: from the mechanistic vision to the holistic understanding of the organizational phenomenon.

A new metaphor results from observing and reflecting theoretically about reality. It has a descriptive and prescriptive character that is analogous to Weber's (2004) ideal types. The metaphor is not a mere reflection of reality in the conceptual world. It is also a resource used to explain it. At the same time, because of its explanatory potential, it may have normative force. Ideal types suggest that in the discovery and conception phases, the role of reality is illustrative. An example of the application of this notion of ideal types is the structural configurations introduced by Mintzberg (1979), in which the presumed coherence between multiple constellations of factors is used for understanding the real structure of organizations.

An example in innovation management is the notion of set-based concurrent engineering. This is a notion that is theoretically constructed from criticism of the previous concept - point based concurrent engineering - and empirically refined by Ward et al. (1995) using a Toyota case-study on product development as a practical source for illustrating what the new concept might mean in management practice. An article by Leonard-Barton (1992), *Core Capabilities and Core Rigidities, a Paradox in Managing New Product Development*, offers us another example. Leonard-Barton uses the cases as an illustration in order to introduce the dialectic notion of a competency that support and at the same time hinders product development.

In this work we have used the fractal metaphor to create a new way of looking at the organizational structure of a large integrated product development project. Observation of the practice, or rather its representation on an organization

chart, started us off on a path of theoretical reflection and led us to re-examine this same practice in order to anchor the new concept in the reality of a specific organization, albeit, of course, in an illustrative way. In the course of our study into the development of products in EMBRAER, we examined the development process of the EMBRAER 170 (YU et al., 2001) and noted the existence of an uncommon structure, which is what motivated this work. At that particular time we carried out nine semi-structured interviews with several managers who are responsible for the EMBRAER 170 program. This final text of ours was validated with EMBRAER.

### 3. The Fractal structure

#### 3.1. Fractals and management

The Concise Oxford Dictionary of Mathematics (CLAPHAM, 1996) thus defines fractal:

“A set of points whose fractal dimension is not an integer or, loosely, any set of similar complexity. Fractals are typically sets with infinitely complex structure and usually possess some measure of self-similarity, whereby any part of the set contains within it a scaled down version of the whole set. Examples are the Cantor set and the Koch curve.”

According to Stewart (1992, p.206), Benoît Mandelbrot developed the fractal idea as a way of producing a model of the geometric structure of irregular phenomena. Fractals are mathematical objects, the property of which is to maintain a similarity of characteristics when the scale of the observation is changed. Its usefulness to describe reality can be seen, for example, when we consider the outline of an island on a map. Seen from an airplane this line represents a fragmented and irregular shape. Seen from a boat, going around the island at a close distance, more details of the coast would be seen, but the line would continue to appear to be fragmented and irregular. Seen under a microscope the line would still be characterized by fragmentation and irregularities. It is the self-similarity at various scales that represents a useful analogy with the needs for integrating and coordinating the hierarchy of the teams involved in a large project.

It is important to see that fractals are a highly regular way of describing the irregularity in certain natural objects. Furthermore, as Stewart (1992, p. 245-247) points out, the infinite cannot be seen in the real world. In nature there are many objects that seem like fractals but for which the scale of observation to infinity cannot be changed. However when the object presents self-similarity at various scales, modelling it via a fractal can reveal its structure and the functions that it has to perform.

Stewart (1997, p. 208-227) himself gives various examples. For instance, the structure of the veins and arteries in the human body, with their increasingly finer blood-vessels, until close to each cell there is a small venous capillary and another arterial one. Or the structure of plants: trunk, branches, twigs, leaves and small stalks on each leaf, successively sub-dividing. Or the internal surface of the lungs, clearly organized in such a way as to allow the maximum contact between the blood and the air, to permit maximum volumetric efficiency when it comes to exchanging carbon dioxide and oxygen between the blood and the air that is breathed out; in other words, it is folded and refolded countless times to maximize the surface that fits within a person's chest. The author (STEWART, 1997, p. 227) shows several examples of the application of fractals in such diverse areas of science and technology as the fractal geometry of the surface of proteins, the electrolytic deposition of metals, the forced extraction of oil, the large scale structure of the universe, computer graphics, meteorology, turbulent flows in liquids and deterministic chaos dynamics.

The property of self-similarity at differing scales, which is so innovative in mathematics and so fertile in applications, is a new way of looking at and describing nature. It differs sharply from the simple and regular geometric shapes that have been used since the time of the Greeks. As Stewart (1997) reminds us "Fractals reveal a new regime of nature susceptible to mathematical modelling. They open our eyes to patterns that might otherwise be considered formless. They raise new questions and provide new answers".

The idea of fractals has already been used in management by Warneck and Huser (1993) in creating the notion of the fractal company and when they used it to talk about a fractal approach to object-driven self-organized corporate units (WARNECK; HUSER, 1995). VENKATANDRI et al. (1997) also used the notion to suggest a fractal layout as an alternative to organizations that produce products or processes. MENEZES (2002) used fractals for a "pragmatic vision of the fractal company", the title of his case study.

SPIVEY (1997) establish a relationship between the theory of fractals and the development of new products. They studied a Research and Development Laboratory belonging to the Federal Government of the USA and observed that the development of a new product involves both the management factor and the resources factor. The management factor divides up into sub-factors, such as leadership and the management system, while the resources factor involves aspects such as information, infrastructure, time and money. According to the authors, these factors and sub-factors must be continually managed at all levels in the organization to ensure the success of the new product. This is where we find the fractal character of the proposal, in the self-similar reproduction of certain factors at all levels in the structure.

A logical step is to try to apply fractals to understand the high performance, adaptive, organizational structure of product development.

### 3.2. The fractal structure

In the concept phase, work on a project is multi-disciplinary, but restricted to a small group of high-level specialists. This is the step when the product tree is created, albeit without any accuracy as far as the definition of interfaces is concerned. In complex systems the product tree has many levels that range from sub-subsystems all the way down to components. At every level there are specifications and interface documents that are absolutely essential for dividing up the intellectual work that characterizes the development efforts of such equipment. Once the product tree has been defined a natural organizational structure for the program then emerges. The natural thing is to attribute each subsystem, equipment or component to a group that will have technical, cost, and timescale goals in the management documents.

Therefore, in a large development project, the time always comes when large teams are necessary. This large team is hierarchically organized and broken down into smaller teams that take care of the various parts of the project. To define the work and the division of work and responsibilities, the work breakdown structure - WBS - is created based on the product tree.

In the past this hierarchical structure was always thought of as defining the responsibilities of the leaders of the sub-projects, equipment, components and other activities. Over the last ten years, however, there has been an emphasis on the need for a multi-functional team for managing large projects.

But why not imagine that instead of just one team managing the program from the top one could reproduce this multi-functional team structure at various levels in the WBS? In other words, why not have a team responsible for each of the levels and divisions in the structure? This is where it appears the idea of management cells for all those sub-systems, components and other activities.

This is also where it comes in the property of inter-scale self-similarity of fractals. Why not organize these teams in a similar way? In other words why not include in each of these management cells the main functions that are necessary for integrating and coordinating the project? After all, as GERWIN; BARROWMAN (2002) remind us, the typical performance objectives of a product development project are intermediate integrative objectives, relating to the time of launch, the product, the cost of the development project and the unit cost, quality and the general performance of the product being developed.

Therefore, in this work, the fractal structure is a geometric metaphor for the idea of a hierarchy of managing

teams – management cells – with different missions but with a similar composition that is reproduced at various levels in the structure of the division of project activities, as illustrated in an abstract way in Figure 1.

## 4. The fractal structure of the Embraer 170/190 program

### 4.1. EMBRAER

EMBRAER produces complex and technologically sophisticated capital goods. Airplanes have a high unit value and a long life cycle (decades), being designed for technically sophisticated civil and military user organizations. Embraer’s main customers are regional air transport operators. In this segment, when it comes to defining a purchase, operating costs, financing and customer service are the key concerns.

The company started out as a state-owned organization. In the nineties it was privatized. When this happened EMBRAER brought with it a strong technological tradition but was weak from the management and financial point of view\*. At the time of privatization the company was selling the highly successful EMB 120 Brasília turbo-prop airplane in the regional aviation market. It was also developing its first regional jet, the ERJ 145.

Embraer works with small-scale production – from a few hundred to just few military aircraft – and with many suppliers. Many of these suppliers are abroad and are major global players. Therefore the company chose to assume the role of solutions integrator in the global market for regional jets.

\* In order to understand EMBRAER’s path prior to privatisation one can refer to Sbragia and Terra (1993). As to the process of privatisation and managerial transformation that went hand in hand with it, this can be studied in Bernardes (2000).

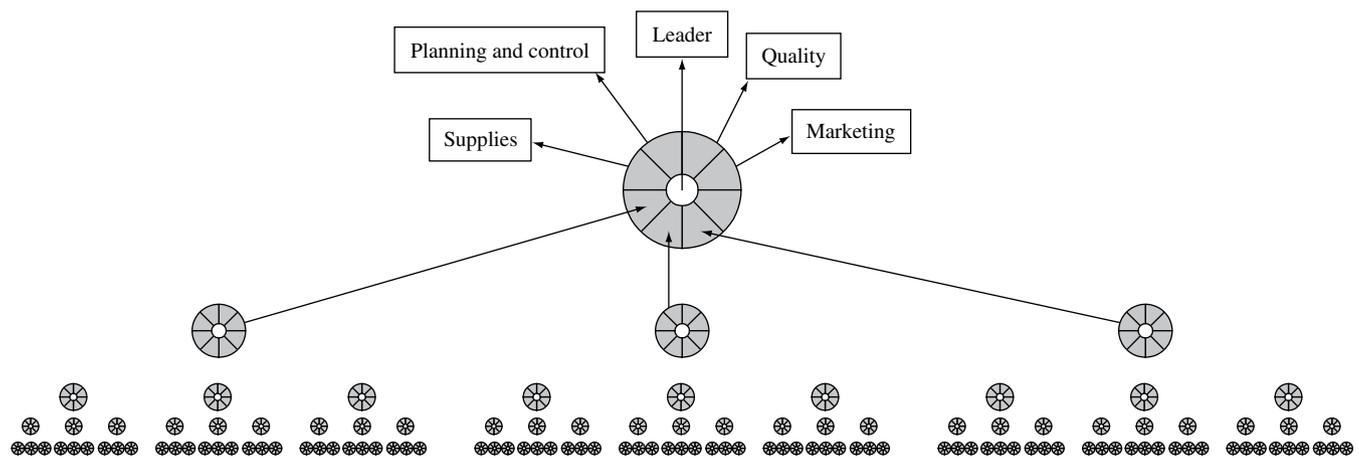


Figure 1. Abstract fractal structure.

### 4.2. Embraer’s regional jets

The 50-seat ERJ 145 has been a commercial success with somewhat fewer than 700 firm orders (www.embraer.com.br, 14/March/05, 4:00 p.m). With the aim of serving its customer-base, EMBRAER developed an off-shoot, the 37-seat ERJ 137 and the 44-seat ERJ 140 jets, thereby making up a family of aircraft. With this success the obvious strategic gap became the lack of products for the larger range of regional aviation, calling for aircraft with between 50 and 120 seats.

To fill this gap the company decided to develop a new family of jets, ranging from 70 to 118 seats. In defining these aircraft the company took into account the following:

- The new family of products should be complementary to the 145 family;
- The typical occupancy rates on American flights;
- The operators extremely demanding operating and economic requirements;
- Contract clauses between pilots and operators that restrict the jets use in USA; and
- The plans of the competitors.

With this, they arrived at the concept of the EMBRAER 170/190 Program; the EMBRAER 170, with 70-78 seats, the EMBRAER 175, with 78-86 seats, the EMBRAER 190, with 98-108 seats and the EMBRAER 195 with 108-118 seats (www.embraer.com.br, 14/March/05, 4:00 p.m). The first commercial flight of the new EMBRAER 170 jet took place on March 17, 2004. The EMBRAER 175 was certified in December 2004. The 190 was certified in 2005, and the 195 in 2006.

The direct competitors of the new family of jets consist of several different companies. In the case of the 170, direct competition comes from the Bombardier CRJ 700 jet. For the 175, competition comes from the CRJ 900 plane. EMBRAER believes that the EMBRAER 170 will

have lower operating costs, a very attractive characteristic for regional operators (GHEMAWAT et al., 2000, p. 8), as well as levels of comfort that are clearly superior to those of the competition. In the case of the EMBRAER 195 the competition will come from the Boeing 737-600 for the 110-132 passengers range and the Airbus 318 for 107-117 passengers range. Both are reduced versions of larger aircraft, which makes them less attractive to regional operators. However, with recent changes in the aircraft market, Embraer jets have become more attractive for the right-sizing exercises that the major and low cost operators are engaged in.

The EMBRAER 170/190 aircraft are technically complex and their development required US\$ 850 million, with a new level of engagement on the part of the partners and customers, and in a more aggressive environment. Their development presented EMBRAER with new organizational challenges.

### 4.3. Integrated development in the 170/190 program

With the 170, EMBRAER found itself in a difficult competitive situation. The program started late and needed to be developed in a record time – 38 months instead of 48, the expected period using the practices adopted on the ERJ 145 project. At the same time, the company could not run the risk of failing to produce an aircraft with characteristics superior to those of the competition. To top it all, the company also lacked the necessary capital. Faced with this situation, the challenge for EMBRAER was a dual one; first, to obtain the funding necessary for the undertaking, and secondly, to develop products in a record time both for the company and for the market.

The first problem was solved by taking risk partners. In developing the EMBRAER 170/190 the company decided to place its bets on partnerships that had not only a financial, but also a commercial and a technological purpose. After devising the EMBRAER 170 (YU et al. 2001), the company tried to find partners and customers to make the aircraft a feasible proposition. Beginning with GE, which assumed responsibility for the engines, and Honeywell, which was responsible for the avionics, EMBRAER brought together an illustrious group of partners that includes Hamilton Sundstrand, Parker, C&D Interiors, Gamesa, Liebherr, Latecoere, Kawasaki and Akros.

To manage the development process successfully and quickly, which was the second challenge, the company adopted the Integrated Product Development process. The aim of the new concept was to go one step beyond Integrated Multi-project Management (AFFONSO; CAMPELLO, 1998), by including the integrated treatment of all aspects into a product development program. The idea was to create integrated processes and to increase the scope of the work of the project teams in order to incorporate more functions

from the rest of the company and even from outside it. In the new vision, from now on the phases of a program formally became the following: preliminary studies, joint definition, detailing and certification, serialization and phase out.

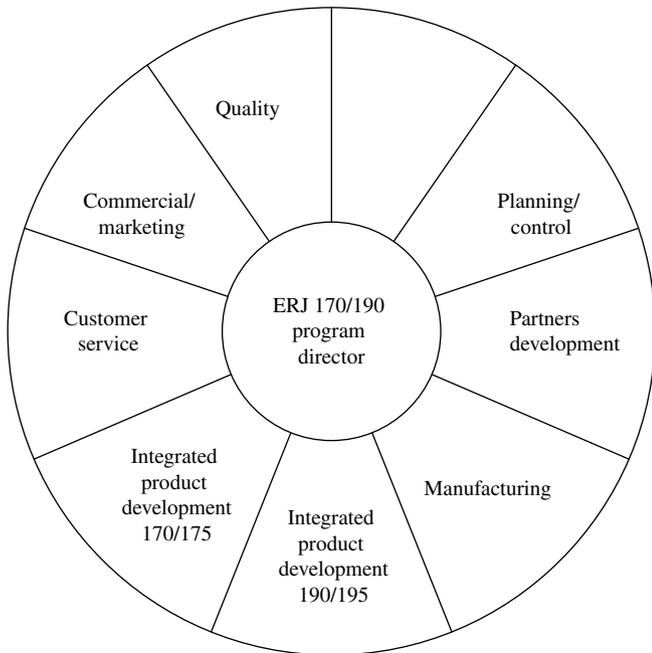
Once the partners had been chosen, EMBRAER moved on to the joint definition of the EMBRAER 170. Bearing in mind the absolute need for a superior aircraft, EMBRAER created a process and a development structure for the program that allowed for the use of concurrent engineering, matrix structure, integrated product development and at the same time the early involvement of partners (1998) and customers (the air transport operators).

In terms of process, the result was to convert the aircraft definition phase, which previously EMBRAER had carried out alone, into a joint effort. EMBRAER and a previously defined group of partners jointly carried out development of the 170/190. The Joint Definition Phase is where the functional and physical integration demands for the aircraft and its systems are detailed. This is a fluid step during which the requirements for each partner are defined and thereafter negotiations for their change become much more difficult. The requirements are defined for each system and sub-system and are converted into formal development goals that are recorded in specification and interface documents. In terms of structure, management cells within the matrix structure were adopted, which brings us to the theme of this article.

### 4.4. The fractal structure of the 170/190 program

The EMBRAER 170/190 Program is managed by a cell (Program Management Nucleus or Core Team) of 10 people headed by the Program Director, as can be seen in Figure 2. For each of the aircraft (170/175 and 190/195) there is a Chief Engineer and everyone takes part in the program's managing cell. Besides this, representatives from the Quality, Planning and Control areas are also part of the cell. In each cell there was someone responsible for Organization & Processes, but currently this person's functions have been taken over by Planning and Control. Above this managing cell stands the Industrial Vice-president. For the purposes of decisions regarding investments, however, the decision centre is EMBRAER's Board of Directors. This is where the main decisions about investments were formalized. Authorization for starting studies of the new concept, authorization for setting up a group for devising the new aircraft, the search for partners and the authorization to create a new program were the Board's main decisions in the development process; the Board also strategically monitors the program.

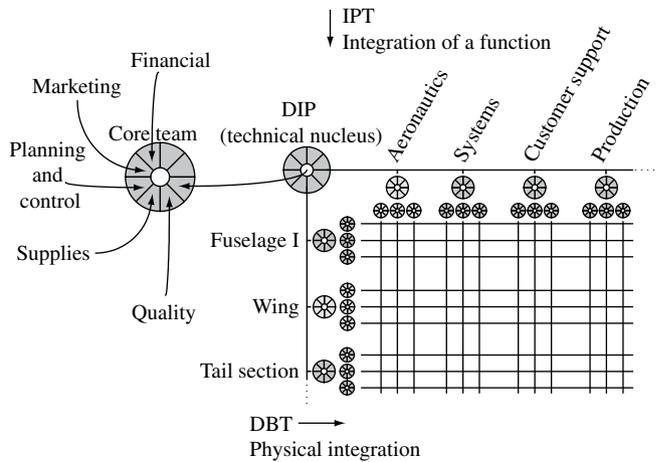
Each Chief Engineer, in turn, heads a management cell for his or her aircraft; this cell is called the Technical Nucleus, as shown in Figure 3. Various Product Development Managers ("GDPs") take part in this cell. There is a



**Figure 2.** ERJ 170/190 core team. Note: The blank cell was added just to represent the possibility of other functions eventually required

“GDP” for Aeronautics, another for Structures, one for Electrical/Electronic Systems, etc. Some of these Product Development Managers are responsible for DBTs (Design/Build Teams<sup>2</sup>, or parts of the aircraft) and others for IPTs (Integrated Product Teams, or integrated systems, such as aeronautics or structures). The function of the DBTs is to guarantee that the aircraft can be physically assembled. In other words, functional sub-systems are spread throughout the aircraft and someone needs to ensure that when they are ready they all fit and work in the way they were expected to when assembled in the aircraft. Each DBT is responsible for a physical segment of the aircraft (nose, tail, etc.). The IPTs take care of the functional aspects, i.e., their role is to guarantee a good project as far as the sub-systems of the airplane are concerned: the propulsion sub-system, the electrical sub-system, the hydraulic sub-system, etc. In turn, each GDP heads up a cell that has to do with its unit. For example, the Aeronautical GDP leads a cell made up of elements linked to IPTs such as aerodynamics, flight quality, performance, etc.

It is important to point out that Figure 3 is a simplification of the real structure. In all the teams Embraer is the leader and the partner is present, whether they be systems teams or segment teams. Therefore, the structure formed by cells operating in a matrix-like fashion goes beyond the bounds of EMBRAER to interact with other structures in other companies in different countries, with different languages and cultures. As a consequence, the composition of the



**Figure 3.** Organization EMBRAER 170/190.

aircraft parts development cells needs to be similar to the ones at other levels of the WBS. This is what the circles in Figure 3 represent. Considering the product tree levels as a discrete dimension we can talk of an organization that, with slight modifications, is maintained at the various levels. In a full representation of the program’s organization however, the need arises to expand the figure to other levels of the product tree.

It is here that the idea of fractals reveals its usefulness. It is fundamental for showing the idea that functional and physical integration does not only occur at the level of the program as a whole, the zero level of the WBS. On the contrary, as the product tree develops at each level the teams need to reproduce a similar internal structure, by incorporating concerns with production, marketing, the wishes of the customer, engineering, technical assistance, ease of use and maintenance, etc. This succession of cells, which are repeated at different levels, suggests the theory of fractals. Obviously, although the general format reminds us of the theory, these cells are not identical (as in the case of fractals) due to adapting needs at different levels in order to face up to the specific managerial and technical details. Furthermore, they do not extend into infinity. There is a final level in the WBS, represented by individual responsibilities.

## 5. Discussion

When observing the operation of the fractal structure in the EMBRAER 170/190 Program we are led to ask in what way the new metaphor contributes to the management of integrated product development. The reply is that the fractal structure offers an organizational basis for the integrative functions that are essential to integrated product development. In large development programs of complex products the division of work is in turn also complex. As the product does not exist and making it requires

sophisticated and specialist intellectual work, there is a need for an intellectual division of work. Fortunately the initial intellectual work of devising the product in small groups contributes to creating the structure or the product tree. When it is ready, this naturally suggests the intellectual division of the work. In both cases the division of work becomes more refined as the program progresses. The same product structure serves also as a guide for structuring the management division of work or the administrative structure. In other words, following the product structure, there are always some natural configurations for the program hierarchy.

How, therefore, is all the work planned, coordinated and controlled when it is thus divided? In other words, how is executed the work in order to achieve the objectives of integrated product development? It is in this integrative management aspect that the idea of the fractal structure brings in its contribution. Normally, the coordination and integration of divided work is the responsibility of intermediate leaders in the project's hierarchy, supported by groups of staff, *ad hoc* committees and formal systems for planning and control. In fact, in simple hierarchical structures the major responsibility for integrative activities and decisions belongs to the project's hierarchy. But in large projects, the greater the competitive pressure, the more useless it is to expect that managers in their structure are capable of performing this integrative role on their own. If, on the contrary, each manager in the intermediate hierarchy is part of a cell that includes people who deal with the main intermediate performance objectives and the management and technical themes that are most relevant to the integration and performance of the project, this is the way a systematic means is born for substituting the impossible need for supermen capable of omniscience, omnipotence and omnipresence for the practical aspects of similar multi-functional teams at each point in the hierarchy. This is why management cells are important. Except now, the functional hierarchy of the program begins to look like a tree of cell upon cell, with a growing number of cells at each level in the hierarchy. And the cells have a similar composition.

Obviously the notion of self-similarity, unlike the ideal objects of mathematics, cannot be precisely applied, above all because in the world of administration infinity does not exist. The product tree finally comes to an end with a greater or lesser number of levels. Its composition also changes because the nature of the concerns that motivate the various levels in the hierarchy change according to the level in the hierarchy. At the top, issues regarding the business and customer satisfaction as a unitary entity are basic. At the bottom, the technical and operational aspects of the project dominate. Therefore the composition of the cells may vary according to the level and type of item, which they

look after. When seeking to reflect upon functional topics, external and internal customers and the intermediaries that link the project to them are fundamental. For example, when taking care of the development of parts and components lower down in the product structure, technical aspects predominate. Therefore, in practice we have to think of a differentiated fractal structure.

Another important aspect to remember is that the fractal structure is a result of the scale, the number of people and the complexity of the programs it is dealing with. At least in the way we have considered it here, the fractal organizational structure is something that only makes sense in large development programs. Furthermore, every program starts small, with a small group of people conducting the devising and initial planning steps. So the fractal structure emerges at the stages of the program in which it begins to use large expert teams. In the case of EMBRAER, the fractal matrix was hugely important at the joint definition phase, during which 600 engineers interacted intensely. In the prior phase, the product concept was defined involving only 20 people. A multi-functional team was all that was needed. If devising the project is a phase of work for a small team, in which coordination via the management and direct communication predominate, it seems reasonable to enquire whether EMBRAER's programs should not have a variable structure over their life cycle and be more closely akin to the fractal structure during the aircraft development phase, above all in the program definition stage and in particular, if there is joint definition. In other project phases, such as engineering detail design or production, the metaphor of a project-like or functional matrix might perhaps produce a better performance.

As we took the idea of metaphors from Morgan, it is worthwhile to recall that, the fractal structure has nothing to do with his holographic organization. The holographic image comes from consideration of laser image processing and an analogy with the brain organization. In this concept every part of the organization has all, or at least many, of the functions of the other parts. This idea is more useful if the organization has similar missions for its cells. For instance, in a missionary organization, like a leftist political party or an evangelical church where each cell would be responsible for the same proselytising activity inside a certain social group. Nothing is further from the fractal structure here suggested. Here, one is dealing with an organizational support for integrative work among functions widely differing one from another. Some cell members would be responsible for integrative intermediate objectives, while the rest of the cell would be specialized in the functional development work of its subsystems or components. There is no hint of self-organization, neither of graceful degradation of functions, as in the holographic metaphor. The fractal

metaphor is specifically concerned with the managerial integration of the development effort, and just that.

It is also important to realize that, if the approach may be used together with the platform team approach, it does not substitute for it. The platform team approach, as used in Daimler Chrysler today, for instance, is a way to divide the development effort of a lot of technically related projects among a few platforms. That is not the purpose of the fractal approach. Here, one is dealing with just one very big project at a time. And one is very concerned indeed with the prospect that it will not achieve its integrative development targets because these targets are not sufficiently acknowledged at the several levels of the work breakdown structure as well as the different subsystem and component sub teams. Although, in the Embraer example, the articulation of several projects into a single product family uses the concept, this just tells interested researchers that the approach is not incompatible with the platform approach. However, its main function is managerial integration of a single very big development project.

With these reminders, the fractal structure emerges as an organizational support tool for P&C systems and for the integrative activity of the manager at the various levels of large projects WBS. The new metaphor provides an organic basis for the integrative aspect of managing large projects.

## 6. Final thoughts

Inspired by Morgan (1996), we have tried to construct a new geometric metaphor based on the property of the self-similarity of fractals. This new analogy helps us to better understand how the organizational structure can help one to deal with the problems of coordination and integration in the quest for high performance in large product development programs.

The theoretical conclusion is that the fractal structure offers an organizational basis for cross-functional coordination over the whole WBS and for planning and management systems that usually are based on the project hierarchy. In other words, in large programs the fractal structure offers an organizational basis for integrated product development.

In particular, the matrix and fractal metaphors of the structure point to different concerns in the management of large programs. The matrix metaphor emphasizes the problem of the division of responsibilities and power over the resources of the organization and over the degree of freedom the project hierarchy has when it comes to innovating administratively and allocating resources. The fractal metaphor emphasizes the need for certain performance concerns to be present at all levels of the product tree so as to ensure the integration that promotes high performance when it comes to product development.

In practice both metaphors are necessary for devising the concept of the structure of large development programs in large, complex organizations. Perhaps it makes sense to talk about a fractal matrix structure.

### 6.1. Limitations

What we have seen in this work indicates that the notion of the fractal structure is only useful in complex projects. Complexity in this case refers to the product and to the technology, as well as to the WBS of project activities. We must also underline a fundamental care that needs to be taken when linking the idea of the fractal structure with the matrix structure. On the one hand it helps us understand the concept of superimposed matrices and on the other we must make clear that the cells will never be able to be an exact copy at their various levels. This would produce a rigidity in the organizational structure that is incompatible with the need for adapting the type of matrix and the balance of power between its axes to the specific needs of each level. This flexibility is the key to an effective organization.

### 6.2. Implications for future research

There is much to be studied to achieve a better understanding of how to structure large and complex projects. This work is an effort to contribute to this end by analyzing a practical case of success that has an unusual management structure. It is especially worth asking about the role of the fractal structure at different stages of a development project. Another point to be investigated has to do with the possibility that the use of management cells might be happening in other complex product development programs so that the notion might have been put to use in practice, as it is in EMBRAER, without it ever having been a formal structure. As Gerwin and Barrowman (2002) indicated, this matter needs to be investigated by researchers in administration.

Finally, the use of the fractal metaphor does not represent the only way of theorizing about the structure we have seen in the ERJ 170/190 Program. Another, more conventional way would be to combine matrix structures with management cells, as a way of providing unity to management concerns at all levels of the WBS.

### 6.3. Managerial implications

The fractal structure appeared as a response to the need to accelerate the development of the ERJ 170/190, which called for the integrated development of a family of aircraft. The joint definition of a complex product, such as an airplane, requires a high degree of interaction between all the teams and all the companies involved. Possible customers, with their different levels of requirements, have to be included in the process. In the case of the 170/190, the customer

was included in the project by means of the Advisory Board and the Steering Committee meetings. Furthermore, the specializations involved in the development of sub-systems, equipment, components, etc. are often similar. The organization that emerged needed to respond at the various levels of the product tree to these needs. The result is a fractal structure that allows for the establishment of a similar structure on the various scales (systems, sub-systems, equipment, components...) of the product tree. This similarity refers to the functionally similar composition of the teams at the various levels in the hierarchy. For the practitioner, who is busy planning the organization of a large development program, the fractal structure is a means of selecting some key concerns and ensuring that they will find room at all levels of the program management, exactly those that are explicit in the program's management cells.

Generally speaking, the main positive aspects of the fractal structure, as compared to the former structure used by Embraer, were: a) a reduction in the total development time of the 170/190 Program, b) a reduction in the cost of rework in the project phase, which should happen also in the production phase, and c) a clear statement of management concerns in the structure of the management cells in the structure of activity division. All this brings about a more effective integration.

The complexity of the fractal structure calls for certain important prerequisites. One of them is the need to prepare people for using it. Training in leadership, teamwork, project management, matrix structures and cells are some of the priority topics. Another fundamental aspect is attitude. Complex structures raise the conflict level, which reduces performance if the destructive side is emphasized. Organization charts and procedure manuals are not sufficient if there is not a general attitude of constructive criticism and collaboration.

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