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Complexity management and supply chain performance assessment. A field study and a conceptual framework☆

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Abstract

This paper presents the results of an empirical research program devoted to investigate how complexity can affect a manufacturing company's performances, and those of its supply chain. In-depth industry case studies involving 14 Italian companies at different stages in the household appliances industry are here presented: more than 200 numerical data and 50 descriptive questions were asked to eight different key managers within each company, focusing on sales, inbound and outbound logistics, product and process engineering, production and organisational issues. Empirical evidence confirms that the way companies handle their operations system complexity has a deep effect on how well they perform.

Relying on these first evidences, a research refinement is proposed by means of a careful classification of complexity sources on one side and of complexity control levers on the other. Then, a first interpretative and theory building attempt is done to set relationships among the operating context, the adopted managerial levers and the operating performances achieved. The model suggests that the ability to control complexity within manufacturing and logistic systems can be regarded as a core competence in order to jointly improve efficiency and effectiveness at a supply chain wide scale.

Keywords: Complexity; Supply chain; Case studies; Conceptual model

1. Introduction

Innovation, globalisation of markets and increasingly demanding customers are trends manufacturing companies cannot escape. So they have to supply a growing mix of products, with features more tailored to customers' individual needs, both in terms of products characteristics and of support services. This relentless effort has caused a ballooning in the complexity of supply chains: wider product variety, smaller production lot sizes, more tiers and different actors to co-ordinate within each supply chain, etc. As an example (see Clark and Wheelwright, 1992), in the mid-1960s the Chevrolet Impala was the best selling car in the USA, and the platform on which it was based was selling 1.5 million units a year; in 1991 the best selling car was the Honda Accord, and the platform on which it was based was selling 400 000 units a

☆This paper is the result of research collaboration among authors. Nevertheless, Sections 1 and 6 were written mainly by Marco Perona, while Sections 2–5 were written mainly by Giovanni Miragliotta.

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year: a decrease by a factor of four despite the increase in the overall market size. So, competition now involves producers as well as suppliers and distributors, thus making the overall system more complex to be managed. Thus, the control and management of this increasing level of complexity can be regarded as a strategic issue for companies.

This remark highlights the need to tackle complexity as a managerial issue on its own. For instance, it is unknown, at current state of the art, how to define and measure the complexity of a manufacturing or a logistic system; how and if this complexity can actually affect the system's performances, and therefore which advantages and how they can be gathered by better coping with complexity. This paper comes as an early report from a specific research program pursuing exactly these objectives; to this extent, the Italian househould appliances sector was used as a test bed.

More specifically, the paper focuses on the presentation of some empirical results and on their interpretation. To this extent, the paper is arranged as follows. Chapter 2 discusses an introductory background of the research, portraying the existing body of knowledge about this topic. Chapter 3 introduces the new empirical research aimed at collecting new data concerning this matter, and Chapter 4 discusses some of the most interesting outcomes. Finally Chapter 5 presents a conceptual model conceived to provide an overall interpretation of relevant variables and management policies devoted to complexity control, while Chapter 6 discusses some concluding remarks.

2. Background

2.1. Conceptual aspects

What does complexity mean? Some may think that complexity is merely the opposite of simplicity; others may think that complexity is a synonymous for complicacy. Actually, both these definitions are wrong, especially the second one. "Complicated" and "complex" both come from Latin words, but the first one originally means "of things knotted, entwined with each other", while the second one means "of things which interact among each other". So, to understand a complicated system all there is to do is to subdivide it in all its single elements: then, treating each element separately will lead to the solution of the problem. This is actually what happens, for instance, with a system of linear equations: no matter how big is the system, a "complicated" procedure is all you need to solve it. Conversely, complex systems are made up by single elements which have intimate connections, counterintuitive and non-linear links: as a consequence, complex systems present self-emerging, often chaotic, behaviours (Forrester, 1961). Thus, understanding the functioning of each single part does not imply to understand the whole system. A non-linear differential equation, or a human community, are good examples of complex systems.

From a manufacturing company's point of view, complexity arises because of the variety which exists within the boundaries of its supply chain. Each aspect of variety is linked with many others: for instance, the choice of putting on the global market a very rich variety of finished products requires to master a wide amount of different and equally demanding technologies; to control and exploit many different sales channels; to deliver to a large amount of logistic customers; to manage a large variety of different subgroups, components and raw materials. In turn, to manufacture a wide mix of components, subgroups and final products, together with the need to deliver them to many different customers in various ways, might trigger the need to manufacture them in different locations, and in smaller batches. Non-repetitive manufacturing in small lots could turn out to be a constraint when it comes to process automation, while the wide variety of components to procure could require to interact with a large amount of different suppliers, globally located.

Variety is a well-known managerial subject: remarkable works have been devoted to discuss how variety of products, of distribution channels, of suppliers, of components, etc. can enhance the competitive strength on one side, but increase coordination and management costs on the other, up to the point of more than counterbalancing those benefits. The managerial area in which the concept of complexity has been more deepened is operations management: broadly speaking, Lean Production and JIT manufacturing (see Womack et al., 1990) basically aim at reducing complexity, under the principle that "the leaner, the better". Endless literature can be found on these principles (cf. Schonberger, 1983), and most of the innovative ideas and techniques developed during the 1980s have now de facto become a standard in the production management playground. Another area in which variety control has been deeply studied is that of new product and process development. Variety reduction program (cf. Suzue and Kohdate, 1990; Galsworth, 1994), modularisation (cf. Ulrich and Tung, 1991; Sanchez and Mahoney, 1996; Baldwin and Clark, 1997), group technology and cellular manufacturing (cf. Suresh and Kay, 1997), product platform design (cf. Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998), mass customisation (Pine et al., 1993) and value analysis (cf. Pahl and Beitz, 1988; Value Analysis Incorporated, 1993) have become everyday life words for engineers and designers. In addition, also marketing experts have dealt with complexity: for instance, Quelch and Kenny (1994) state that unchecked product line extension can weaken a brand's image, disturb trade relations and cause cost increase; in fact, even if marketing managers may see an overall sales increase, manufacturing and logistics managers may be overwhelmed by the additional complexity: as a global effect, excessive line extension will lead to lower brand loyalty, stagnant category demand, poorer trade relations due to the increase in space requirement, etc.

2.2. Empirical evidences

As it was mentioned in Section 1, a comprehensive perspective on the relationship between complexity and business performances is still lacking, and very few research works concerning this issue can be found. One of the most interested studies in this domain is that one of Adani et al. (2002), focused on the diffusion of supply chain management practices over three important Italian industries, namely household appliances, fashion and the book publishing. As a by-product of their investigation, these authors found out that in each studied industry, the best performing supply chains were always boasting the lower complexity level as compared to industry average: with reference to household appliances Table 1 shows a resume of main data collected for Italian manufacturers of components and OEMs.

These findings help to highlight that there is a correlation between some parameters that can be linked to variety and complexity control and company performances. Nevertheless, they fail to explain the direction of this correlation, leaving unsolved whether it is complexity reduction which leads to better performances or a greater availability of resources consequent to good performances which eases the achievement of lower complexity. Moreover, since this research was aimed at different objectives, it cannot explain how the aforementioned connection works.

Table 1
Empirical evidences from Adani et al. (2002), regarding Italian household appliances supply chain

Subsample	Best practice	Average sample
Observed complexity-related variables		
Components standardisation index	8.6	6.6
Number of finished products (OEM)	900	980
Average order size (units per order line, suppliers)	15 000	3 700
Number of suppliers (OEMs)	132	471
Number of customers (suppliers)	41	87
Number of intermediate products (suppliers)	385	710
Operative performances		
Components running capital costs (% turnover)	0.1	0.8
Obsolescence costs (% turnover)	0.1	0.5
Finished products running capital costs (% turnover)	0.1	0.5
Transportation costs (% turnover)	1.0	1.4
Administrative costs (% turnover)	0.3	0.8
Economic performances		
Operating profits (% turnover)	12.4	4.2
Avg. yearly urnover increase of	20.6	13.1

Furthermore, this lack of interpretative ability is not compensated by existing literature; worse still, managerial literature is unable to provide clarification about measurement approaches suitable for assessing the validity of an action made to control complexity: for instance, while Stalk (1988) says that a 50% decrease in end items variety can trigger an increase in productivity by 30% and a decrease in costs by 17%, Hardle and Lodish (1994) present examples where product line extensions raised whole company performances. These apparently controversial results highlight the likely existence of a certain amount of "useful variety" (able to increase sales more than costs), and on top of that of some "harmful variety", that does not really create customer value, while actually increases internal costs. Furthermore, complexity reduction is not the only way to deal with complexity: it is also possible to reduce its effect. For instance, Suzue and Kohdate (1990) proposed five techniques to decrease the number of parts in a product and diminish the number of operations required to manufacture it, without affecting the variety of finished items: this allows to decrease internal complexity without affecting the market, and once more underlines that smart management of variety can shift the trade-off equilibrium among efficiency and effectiveness by improving both simultaneously.

So what is actually lacking is a model able to explain the relationships among all relevant variables and to address company's efforts in reducing or in managing complexity. Moreover, unlike the bulk of works presented in literature, which address complexity with a partial view (finished products, components, production processes, etc.), a comprehensive view on the whole company and, even more interestingly, on the whole supply chain is also missing.

3. The empirical research

This section presents the main features of the research programme that undergoes this paper. To this purpose, Section 3.1 presents the objectives and the consequent plan followed to accomplish them; Section 3.2 reports about the methodology used to collect and elaborate data and Section 3.3 describes the main features of the sample of interviewed companies.

3.1. Research plan and objectives

Starting from the issues discussed in Section 2, this research was set to overcome the aforementioned limitations of currently available research, by pursuing the following set of objectives, and the connected action list.

(i) *To describe* how manufacturing companies cope with complexity in their supply chains, and how the different ways the problem is coped with can affect local or global performances. This first objective was pursued by directly collecting a wide amount of data about complexity drivers, control levers and process performances from various functions in the company and from different companies within a single sector, but at different tiers in the supply chain.

(ii) To propose an *interpretative model* designed to define and classify complexity dimensions and sources, as well as control levers and connected performances. In order to fulfill this second objectives, a wide and deep analysis of collected data was performed jointly with the retrieval and organization of previous knowledge in this field.

(iii) To propose a *normative model*, designed to understand logical connections among the adoption of specific complexity control levers and results achieved. This final result should support managers in identifying their approach toward complexity by knowing what can be done and which results could be expected. To achieve this result too we relied on the empirical analysis of collected data, by means of the previously mentioned interpretative model.

3.2. Data collection methodology

Given the above stated objectives, we decided to resort to extensive transversal case studies, since they ensured higher quality in collected data, if compared to mail surveys. Moreover, case studies are suitable for theory building and allow to collect non-quantitative data also thus better supporting the achievement of the second objective stated in Section 3.1.

Data collection was performed through in-depth interviews, structured in accordance with a standard form which helped the interviewers and interviewees to concentrate on exactly the same aspects at each meeting. The form was beta-tested on few companies in the early steps of the research project before it was finally released for use.

Multiple respondents were selected for each interviewed company: in this way we increased the availability and the quality of the gathered information. Selected respondents were: the company's CEO or anyway the boss of the considered business unit; functional managers in charge of the following Departments (no matter how called and arranged within different organisations): Sales, Procurement, Distribution, Production Planning and Control, Product Engineering, Process Engineering, Quality, and Accounting; moreover, we also interviewed the manager of each considered manufacturing plant.

In order to accomplish data collection operations with the maximum speed and ease, we proceeded to e-mail or fax to each considered manager his or her relevant section of the form, a couple of weeks before interview. Then, a support team supplied phone assistance in identifying and debugging tricky questions, as well as in addressing the retrieval of mostly required data. Interviews were carried out in one daily shot, with two or three teams in parallel: firstly, a joint meeting of researchers with the respondents team was held to share a common view on some questions as well as to fix the workday's timetable; then interviews took place; finally, at the end of the day a 2-hour debriefing meeting of researchers was held in order to share and discuss all data collected (or not yet collected) and fix an action list accordingly. Starting from the day after, all collected data, opinions, and aspects were coded within two documents: the central data-base (on a simple excel table), and a word document containing the complete resume of the interviews. All quantitative and non-quantitative data were processed by means of a standard set of cross-checks, and all inconsistent or non-clear aspects sorted out with the corresponding manager, either via phone or through a follow-up interview: more than half the companies required a second interview in order to complete data collection, while not all of interviewed companies were in any case able to supply all required data.

Given the methodology adopted for data collection, it is important to underline that no inferential statistical analysis or correlation measure can be provided, but rather a set of evidences supporting the understanding of the inherent relationships among complexity control levers, complexity drivers and performances measures.

3.3. Sample description

The selection of the business on which to test the developed model represented a critical aspect, and this is for two reasons. First, according to research objectives stated in Section 2.3, a supply chain oriented approach should be adopted: therefore the studied industry should allow easy access to many companies at different levels in the supply chain. As a second reason, even if the interviews were an excellent source of information, a significant a priori level of knowledge about the studied business was necessary in order to support the modelling and the data validation phases, as well as to attract companies' commitment.

These two aspects convinced the research team to focus on the Italian Household appliance industry (dishwasher, washing machines, refrigerators and cookers). In addition to the above mentioned advantages provided by this industry, it is a very relevant business for Italy, given its leadership of the European market, with around 50% of OEM's volumes and an even larger figure for components. Moreover, the research team was rather familiar with that business because of previous research experience.

Fourteen companies, including some of the most relevant players in this business, took part to the focus group. As illustrated in Table 2, they were divided into two groups, accordingly with their position within the supply chain. Quite meaningfully, despite the fact that they were as much

Table 2
Sample description (year 2000 data; turnover is expressed in Euros)

Key item	Components suppliers		OEM manufacture	Sample
	Passive	Active		
Number of companies	2	7	5	14
Average turnover	30 000 000	87 000 000	127 000 000	93 000 000
Average no. of employees	236	557	645	568
Average value added (% on turnover)	51	48	31	42
Average turnover trend (%)	+6.5	+3.5	+12.4	+7.4

invited to take part as other companies, none of actors on the distribution's tier was interested.

A further distinction was then made among component suppliers, by subdividing them on the base of the kind of components supplied: thus, we defined passive components as those mainly connected to structural or aesthetical functions, and thus without moving parts (e.g. plastic shell, gasket, cable, etc.); and active ones, mainly dedicated to deliver control or energy functions wirhin a white good (e.g. engine, compressor, controller, timer, etc.).

Table 3
Suppliers' partnership—empirical data

Key item	Partnership		Delta (%)
	No	Yes	
Number of companies	9	4	—
Average complexity index	58	32	−45
Average hours/year devoted by Procurement Department to each supplier	7.2	4.3	−40
Scrap rate for incoming material (%)	0.75	0.1	−87
Average stock coverage, in days	14	7	−50

4. Empirical findings

This section of the paper contains some of the empirical evidences of the research programme described in Section 3.

4.1. Partnership with suppliers

One of the first issues we aimed to assess is how a partnership (cf. De Maio and Maggiore, 1992) with key suppliers can reduce complexity and thus improve company performances. To this extent, one of the 14 companies was not able to provide the required information, and so it was discarded from this analysis. The collected information is displayed in Table 3. The complexity index defined in Table 3 is obtained as the average of two indexes: the first one is computed as the average of the supply relationship duration, and gives lower score (lower complexity) to companies which have more stable relationships. The second one is related to the procurement policies, and gives lower score to those companies which avoid spot contract and focus on rolling ordering mechanisms and therefore are characterised by higher operative integration with key suppliers.

As it can be seen, there is an evident correlation between lower complexity index and the usage of the partnership lever. This correlation stays true also between complexity index and efficiency and effectiveness performances of the supply process: therefore this set of data strongly suggests that investing in partnerships with suppliers can make companies save time in managing commercial transactions, increase transaction reliability and decrease defect rate in delivered goods, things which are the real key to turn on an effective stock reduction process.

It is useful to notice that partnering and keeping stable relationships in time is a value-adding activity to both tiers involved in the relation, which points out a win–win solution. Let us consider two different sub-samples, the first one including all those suppliers which have long-term commercial relationships with their customers and all those producers which have long-term commercial relationships with their suppliers, and the second one including the remaining companies. The collected data, which came from 13 of the 14 interviewed firms, are presented in Table 4.

The complexity index here reminded is obtained as the average of two indexes: the first one, as before, focuses on the procurement policies, and gives lower score to those companies which avoid spot contract, while the second one assigns lower complexity score to ordering policies based on pull and JIT principles.

Once again, data clearly suggest that companies boasting the lower complexity have best efficiency and effectiveness performances. The most interesting result is that one concerning overall stocks at the interface between companies, which are reduced of almost 30% when relations are shaped in the long term as compared to short-term relations. This fact can suggest that decreased complexity could reduce the sources of uncertainty, so decreasing running capital costs. In conclusion, the following remarks stem out of this first empirical evidence:

(i) data in Tables 3 and 4 show that moving toward a stable relation is an effective management lever to reduce complexity;
(ii) this complexity reduction produces remarkable benefits in both efficiency and effectiveness interface performances.

4.2. Product modularisation

As stated in Section 2.1, product engineering is one of the functions which has the largest control on complexity, and this is because it represents one link between marketing and production. In this area, empirical data collected allow us to investigate the impact of product modularisation in improving new product development performances. To this extent, please consider data presented in Table 5.

The two passive components suppliers were discarded because of the nature of their products; moreover one supplier was discarded because of data unavailability. A complexity index, defined as the sum of the number of components and of finished products to be managed, has been computed: as it can be noticed, modular design does not shift in a considerable way this figure, and therefore modular and non-modular companies

Table 5
Modularisation effect for suppliers and producers—empirical data

Key item	Modular design		Delta (%)
	No	Yes	
Number of suppliers	2	4	—
Average complexity index	39	46	+18
Average R&D man hours per new model	97 500	38 500	−60
Average restyled or modified models per year	57	27	−53
Number of producers	2	3	—
Average producers' complexity index	57	54	−5
Average R&D man hours per new model	10 800	8 600	−20
Average restyled or modified models per year	22	14	−36

Table 4
Relationships stability—empirical data

Key item	Commercial relationships		Delta (%)
	Short term	Long term	
Number of companies	7	6	—
Average complexity index	42	28	−33
Average interface stock coverage, in days	29	21	−28
Delivery lead time (days)	25	16	−36

handle more or less the same amount of product range complexity.

Conversely, investing in a modular redesign is connected with a sharp increase of the efficiency performances, represented by the average R&D man-hours devoted to each new model. Likewise a noteworthy improvement in the design effectiveness was found to be connected to modular design, as shown by the reduced number of interventions done on existing models.

Thus, product modularization turns out to be a powerful lever in order to manage existing complexity, rather than to decrease it, and it consistently characterises those companies with the best product engineering performances.

4.3. Information systems for production planning and control

One of the most interesting evidences which emerged from the collected data was that the investment in information systems for production planning and control (PP&C) is a powerful lever to manage complexity. Empirical data regarding this evidence are shown in Table 6. Only one company was discarded because of data unfeasibility; the remaining 13 were divided in two sub-samples according to the fact that they mainly operate with closed production orders rather than with blanket ones, i.e. with production orders which specify only a framework for the production activities, and allow shop floor managers to activate production resources according to their needs.

The complexity index in this case was simply defined as the number of production orders issued per year. We notice that the usage of a PP&C package can increase the complexity level, since more production orders are actually issued. Nevertheless, a relevant improvement can be found in terms of efficiency performances (workforce productivity) and effectiveness performances (frozen period). Therefore, data show that the investment in PP&C information systems is an effective complexity management lever, because it allows to jointly reduce the number of employees involved in the production planning activity, as well as to increase production readiness.

4.4. Summary on empirical findings

The empirical findings reminded here are just a small part of the more than 20 evidences highlighted during the research programme: the good quality of field data, ensured by the selected research methodology, has allowed very consistent and focused analyses on the complexity issue.

The above presented evidences, together with other ones overlooked by this paper due to space unavailability, it is possible to derive the following remarks:

(i) The level of complexity of an operative system was found connected to both its efficiency and effectiveness, ceteris paribus. Thus, it is possible to conclude that by reducing complexity of one operative system,

Table 6
PP&C information systems effects—empirical data

Key Item	PP&C information system		Delta (%)
	No	Yes	
Companies with closed production orders	5	3	—
Average complexity index	80	96	+20
Average production orders per year per production planning employee	6 200	7 350	+19
Frozen period (in days)	6	4	−33
Companies with blanket production orders	54	1	—
Average complexity index	25	37	+48
Average production orders per year per production planning employee	850	1 200	+41
Frozen period, in days (blanket)	4	3	−25

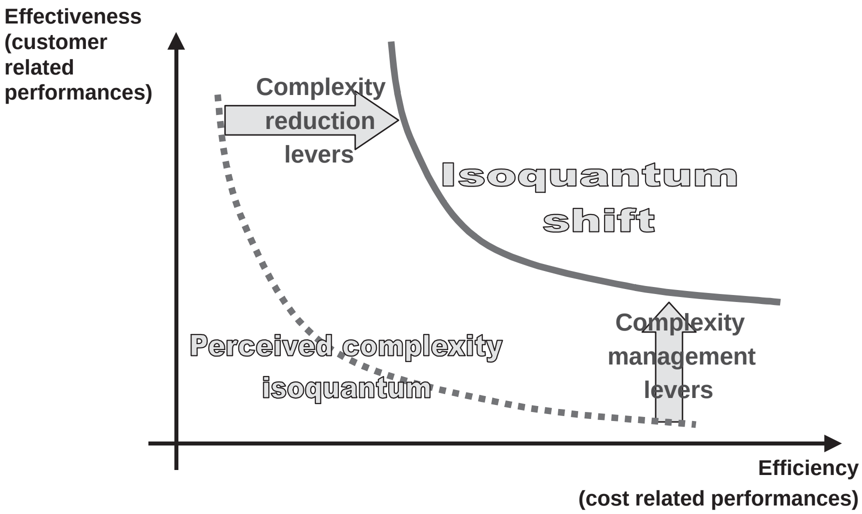

Fig. 1. Impact of complexity reduction or management levers.

it is possible to jointly improve its efficiency and effectiveness.

(ii) Two different kinds of levers can help managers cope with complexity: *complexity reduction* levers, which reduce complexity at a physical level, and *complexity management* levers, which reduce the impact of a certain amount of physical complexity on system's performances.

(iii) Complexity control levers (of both kinds above specified) tend to have an impact on both efficiency (cost) and effectiveness (service) performances. This is an important feature, that shows that complexity control levers are able to shift one company's efficiency–effectiveness trade-off. Please refer to Fig. 1 for clarification of this concept.

To further strengthen the value of the above remarks, it is important to underline that the performance improvements discussed here have been computed for a very focused sample of companies all belonging to the same industry sector. Moreover, these results are a valid basis on which to build an interpretative theory, since they do not only link some complexity drivers (or measures) to process performances, but also help to set a causal relationship between adopted levers, complexity driver and results.

5. A conceptual model for the empirical observations

This section of the paper presents a new conceptual model of operations systems complexity, based on the empirical observations shortly summarised in Section 4.

5.1. Model entities

Starting from the data collected in field and their interpretation, presented in Section 4, a classification of complexity dimensions, sources and managerial levers can be proposed, at least for manufacturing companies. Such a classification might be incomplete, but it actually represents a first modelling effort concerning complexity of manufacturing and logistic systems. Fig. 2 illustrates the dimensions that were considered in order to analyse complexity.

Following the model presented in Fig. 2, the amount of physical complexity (i.e. variables and relationships among them) existing within a manufacturing or logistic system can be classified

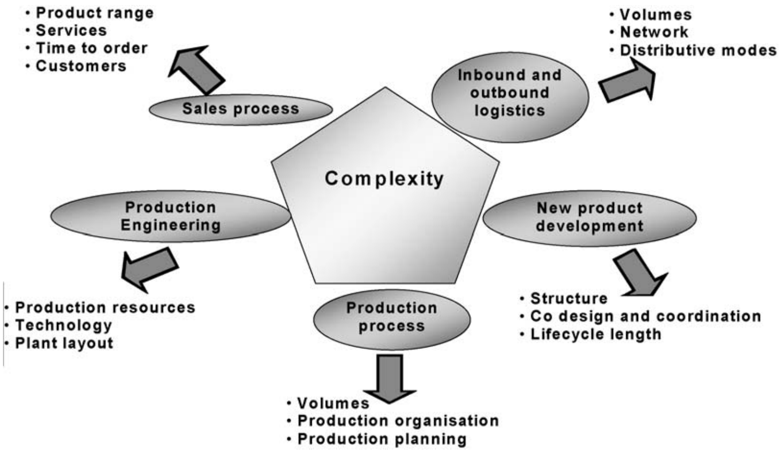

Fig. 2. Complexity dimensions for manufacturing or logistic systems.

Table 7
Example of complexity control levers

Dimension	Lever	(R)eduction/(M)anagement
Sale process	Integrated information system with customer	M
In & Out logistics	Integrated information system with supplier	M
	Outsourced delivery and warehousing	R
	Vendor rating system	R
New product development	Information tool for component re-utilisation	R
	Product modularisation	M
Production process	Information system for PP&C	M
	Automated internal handling	M
Process engineering	Outsourced production	R
	Automated production resources	M

in five dimensions, each of which pertains to a specific business process. For each of these dimensions, then, the performed interviews allowed to point out a wide number of physical drivers which, transformed into indexes, can be useful to quantify complexity. Some of these drivers have been described and applied in Section 4.

Also derived from the performed interviews, we propose a classification of possible complexity sources and, most important, of control levers which can be used in order to tackle complexity. Some main levers, divided following their main effect in reduction and management levers (see Section 4), have been sampled in Table 7.

Starting from this rationalisation of the collected information, a new normative model can be proposed, and will be discussed in the following section.

The last entity we developed in our modelling work were system performances. As seen in Section 4 we defined for each dimension illustrated in Fig. 2 a full set of efficiency (cost) and effectiveness (quality or service) related performances, at both activity and business process level.

5.2. Model relations

Next to defining the main entities that should be considered by a model of complexity of a manufacturing or logistic system, we had to define relations among these entities, that is how the different entities defined can interact in order to

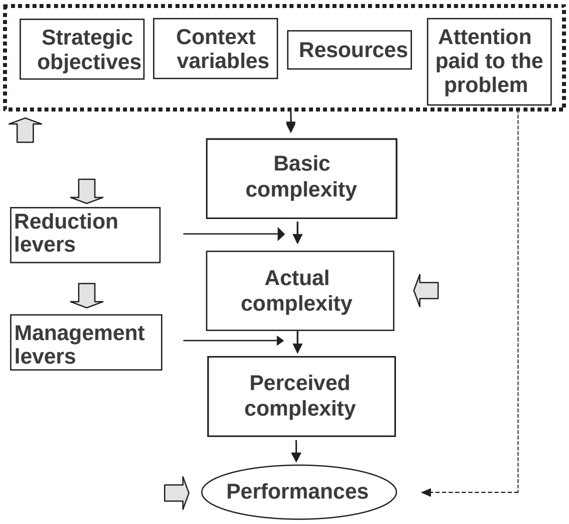

Fig. 3. Complexity model.

determine system performances. Fig. 3 summarises the model derived by a synthesis of our empirical observations.

According to the conceptual model presented in Fig. 3, each manufacturing or logistic system is characterised by some strategic objectives (e.g., to be a service leader, to be a fast follower, etc.), by some context variables (e.g., to belong to a small group, etc.), by its available resources (human, financial, technological, etc.) and by its attention to the various issues of complexity (generally speaking, the care put in controlling and managing variety within and without the system). What comes out of the combination of all these context factors is a certain level of *basic complexity*. This represents the standard amount of complexity which is needed, in a given environment, to reach the stated objectives given the available resources. Thus, we can expect companies that compete within the same geographical market and industry, to be affected by almost the same level of basic complexity.

Given its basic complexity level, a company can adopt some complexity reduction levers which will, in time, produce its effects by reducing the basic complexity to a lower level, which we will define as *actual complexity*. Thus, two companies that share almost the same level of basic complexity, can have a much different level of actual complexity if only to implement a much different pattern of complexity reduction levers.

In turn, each company can adopt also complexity management levers (e.g. PP&C information system), which will not reduce the actual complexity (indeed, they can as well increase it), but will reduce instead the negative impact a certain level of actual complexity can have on system's performances. Given that the impact on performances is similar to that achieved through a reduction in system's complexity, in this case we defined the concept of *perceived complexity*, which is the (unattended) level of complexity leading to the observed performances.

Finally, perceived complexity, together with the context variables, determines business performances. These performances, together with all the other items marked in Fig. 3 with a small arrow, can be observed and, therefore, have been measured during the interviews.

The model described above, and its relations to the data collection and elaboration's methodology employed in this research programme require some further clarifications.

(i) Since it is only possible to measure actual complexity, in order to consistently evaluate the impact of a certain lever on performances, it is important that all the considered firms have almost the same basic complexity. In this research this has been ensured in two ways: first, by selecting firms belonging to the same industry and, second, by pointing out different and coherent subsamples according to the peculiar aspect studied.
(ii) The analysed complexity control levers (both reduction and management) should be considered at the same stage of implementation. This implies that it is incorrect to compare two companies which claim, for instance, of having a product modularisation programme, if the first company has an ongoing project, while the second one has already done it since years. This is a very subtle concept, because the proposed model is time-static, but companies are not.
(iii) With regard to the selection of the performance measures, one should pay attention to

always use very focused measures, so to highlight effects which can be consistently linked with the selected lever. For instance, it could be useless (or even misleading) to use the turnover as a key performance index for the adoption of a long-term partnership with key suppliers, while the stock coverage is a more targeted measure.

(iv) Complexity control should be always studied as a supply chain matter, so attention should be paid to highlight which effects can be perceived only at a single company level (e.g. increased workforce productivity) and which can be perceivable at a supply chain level (e.g. reduction of interface stocks).

(v) Finally, selected performance measures should always include both effectiveness and efficiency data, and this to prove that the applied lever has not simply shifted the trade-off equilibrium point, but has actually reduced the perceived complexity.

6. Concluding remarks

This paper presents some early results from a 2-year research programme aiming at investigating how complexity of manufacturing and logistic systems is linked to their performances, and at providing new interpretative and normative models to evaluate the impact of complexity control levers. This programme stems from previous research results making it clear that companies that most care about controlling and reducing their supply chain complexity tend to achieve superior results within terms of efficiency and effectiveness. Despite the fact that several of the complexity dimensions and levers described in Section 5.1 (e.g. the simplification of the new product development process through modular design and components standardisation) had been already deeply studied, this appears to be the first study that systematically approaches manufacturing and logistic systems complexity from a global perspective. As a matter of fact, the ability to measure complexity appears to be one of the most important and value-adding results of this research, since there are very few attempts, in literature, to develop a consistent set of complexity indicators (cf. Martin and Iishi, 1997).

The study has highlighted that there exist two different kind of levers to control complexity, namely complexity reduction and management levers, whose different effects were described in Sections 4 and 5. Moreover, it has yielded a large base of evidence that, ceteris paribus, a lower level of complexity of the system yields a joint improvement of system's efficiency and effectiveness, showing therefore its ability to shift the well-known trade off among these two performance domains. Despite the fact that results discussed in previous sections were achieved in the white goods sector, we think that they can be easily considered as valid for almost all manufacturing sectors.

Beside these positive remarks, some limitations have to be highlighted. First of all, even if quantitative data on cost structures and on investments required to implement the different levers have been collected, by now no statement on the profitability of each lever has been made; this limitation should be overcome in a refinement of these first outcomes, which should encompass an attempt to innovate cost management systems which, by now, are much too focused on monetary costs (in particular on manpower costs) and give no support in understanding the impact of hidden costs, typically those due to an increase in complexity.

We have also to remind that no statistical analysis or correlation measure has been provided, because depth and quality of information were preferred to the wideness of the data set. In our opinion, this does not actually set a limitation in this very first stage of the research project, in which the theory building purpose represents the main concern.

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