Information flows for high-performance manufacturing

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Abstract

The successful implementation of many management best practices (just-in-time, total quality management, concurrent engineering, etc.) heavily depends on proper organisational communication and information management. In this paper, we address the issue of how these best practices, labelled as high-performance manufacturing (HPM) practices, can affect a firm’s communication structure. The paper firstly develops a reference framework for the analysis of information flows in operations. This reference framework integrates research in operations management and in organizational communication. The paper then applies the proposed framework to investigate how information flows tend to be characterised in HPM. In doing so, the proposed framework relates cost, time and quality performances to three operational processes (physical transformation, product development and material flow management) and to three classes of information flows: vertical, horizontal and external information flows. (2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Total quality management, just-in-time, world class manufacturing, lean production, concurrent engineering, etc. – hereafter broadly labelled as high-performance manufacturing (HPM) – provide companies with a wide range of practices and approaches aimed at achieving higher performance levels [1–6].

The literature on HPM often highlights the importance of communication and information management [1,7–10], but there is a lack of research dealing specifically with these aspects [11]. The great emphasis on communication routines that is given in some recent works [12] is emblematic of the importance of exploring the link between the firm communication structure and its operations.

The opportunity to research this topic does not only arise from a gap in operations management body of knowledge, but has a practical relevance as well. In fact, achieving a thorough understanding of the interplay between communication and HPM operating processes can enable improvements in the effectiveness and efficiency of these processes. Moreover, the availability of instruments for analysing and mapping the communication requirements induced by HPM practices is a prerequisite for taking advantage of the tremendous power of the recent developments of IT, such as enterprise resource planning (ERP) and product data management (PDM) systems.
This article, therefore, has two main objectives:

- firstly, to develop a reference framework for the analysis of information flows in operations;
- secondly, to investigate, on the basis of this framework and of the existing literature, how information flows tend to be characterised in HPM.

This theoretical contribution draws on the apparatus for analysing organisations from the point of view of information content, circulation and elaboration developed in the context of organisational communication research [13].

The paper is structured as follows. In Section 2 a framework for the analysis of information systems in manufacturing companies is developed. This framework relates the firm’s operational performances with some of the its key operating processes and with a set of information flows classes. Section 3 adopts this framework to put in evidence how process-specific information flows can lead to higher operating performance levels. In doing so, for each one of the fundamental operating processes considered, the primary information flows underlying HPM practices are explicated. The Section 4 draws some final considerations on the distinctive characteristics of information flows in HPM companies, and presents some practical implications.

2. A framework for the study of information flows in high-performance manufacturing

Many researchers and practitioners studying and applying HPM practices claim that firms have to become more process oriented if they want to improve their performances significantly [1,3,14–17]. A process can be defined as a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs [16]. Adopting a process view therefore means considering in a holistic way all the activities carried out in the firm, with the primary purpose of obtaining a well-defined output from certain specific inputs [18]. This makes it easier to understand the impact that activities spread across the firm have on the attainment of a certain goal, and hence on the operating performance of the business. Achieving a process orientation, therefore, is often necessary for managerial action to attain higher operating performances. As a consequence of the given definitions, a process can be defined regardless of the fact that its members share responsibilities in other processes, and that they are grouped under the same organisational unit or not. Therefore, companies can be depicted as sets of processes, each of them devoted to the achievement of some well-defined objectives.

Since this paper focuses on manufacturing firms, three broad operating processes are taken into consideration: physical transformation, logistics, and product development:

- The physical transformation process is aimed at physically transforming the purchased materials and at assembling parts and components into final products.
- The logistics process concerns the planning, control and execution of all those activities related to the movement of goods from suppliers, through the plant, and down to customers, including the order cycle too.
- The product development process embraces all those activities directed at improving or designing new products, from the initial emergence of a product concept idea up to production ramp up.

The process perspective can be a useful lens for analysing a company, even though processes do not correspond to formal organizational units. In addition to this, in HPM they are not confined to the company itself, but also involve suppliers and customers, since the performances obtained by the plant are strongly associated to the linkages with chain partners [19,20].

People involved in a certain process continuously exchange information in order to accomplish their tasks [21,22]. Parts of these information exchanges tend to become regularised, involving the systematic sending and receiving of specific messages, and leading to the development of stable patterns of communication [23–25]. These communication patterns can be conceptualised as “process communication networks” and the information exchanges taking place within them as
“information flows”. The concept of “process communication network” integrates both formal and informal communications, and can be used independently of the fact that certain information flows are supported by information technology or not. The process communication networks, as a whole, constitute the “business communication system” [26], and this system serves both as the matrix linking members together in organisations, and as the vehicle by which organisations are embedded in their environments [23].

Analysing the business communication system from a process communication network perspective helps to identify some information flow clusters directly coupled with the process activities, and potentially important for reaching higher performance levels. It is therefore possible to study how each process communication network can support and improve process activities, leading to higher process-related operating performance levels. Organisation Science (OS) researchers have developed many criteria for classifying information flows: purpose/function [23,27], degree of formalisation [28,29], direction [30–33], media richness [34,35], etc., depending on which particular aspect is to be examined.

In this paper information flows will be classified in relation to their direction:

- **vertical information flows** are communications which take place along command chains, both downwards and upwards;
- **horizontal information flows** are communications which do not pass through the command chain inside the company (they mainly cross hierarchy lines);
- **external information flows** are communications which link the company with other channel actors (mainly suppliers and customers).

The first two directions are abundantly studied in the OS literature, and various authors [30,31,33,36] stress the importance of horizontal and vertical information flows when task uncertainty increases. The third direction is added to take into consideration the growing importance of channel co-ordination for reaching higher performances.

Finally, in order to complete the framework, after having included the operating processes and information flow dimensions in the overall picture, the performance dimension should be added (see Fig. 1). Nevertheless, since the focus is on operating processes, only the operating performances cost, quality and time (including flexibility) should be considered [37].

This framework helps to analyse the business communication system in order to identify improvement actions for the attainment of higher operating performances. However, in the presentation of this paper, the association of process information flows with operating performances is discussed – process by process – only in general terms, without making an analytical exploration of which operating performances are associated with which information flows. For this reason, only the information flows-process plane is highlighted in Fig. 1.

3. Transformation process

The transformation process plays an important role in achieving higher performances, since it directly influences product conformance to design, efficiency, and throughput time variability. Both just-in-time and total-quality-management approaches devote great attention to this process: they emphasise the need for achieving better process
control and continuous process improvement. This in turn generates some specific requirements on the information flows that have to take place in the transformation process.

3.1. Information flows for process control

Keeping a process under control means ensuring that the process is capable of meeting the requirements at any point in time and that the correct adjustments to the process, or to its inputs, are done when it is not meeting the requirements [38]. The information flows arrangement spreading among direct workers, specialised personnel, managers and supervisors is heavily dependent upon the control philosophy adopted.

The information flows supporting transformation process control in HPM can be described in differential terms, comparing them with those peculiar to the Taylorist/Fordist paradigm. According to the latter, the people who are ultimately responsible for assuring process reliability are managers, who mostly exert control by relying on the information provided by specialised personnel who gather data from the shop floor, analyse them and finally synthesise them into reports for managers [8]. Another feedback loop takes place whenever direct workers experience serious problems (i.e. equipment breakdowns, manufacturing or assembly difficulties hampering the execution of transformation activities, etc.). In these cases a quicker vertical information flow is triggered, involving first of all supervisors, and then finally managers, while workers wait for instructions or for the intervention of support personnel. Hence, ensuring control through hierarchy means relying mainly on vertical information flows, both upwards (conveying structured information on the process status and ad hoc information on control problems) and downwards (conveying orders, directives, requests for further information etc.). This leads to some well-known drawbacks:

- the continuous flow of reporting and problem-related information overloads managers, increasing the risk that some important information is overlooked;
- the long control loop (operator–supervisor–manager) is not timely, leading to poor and lengthy process control;
- the described communication pattern ignores process-related information retained by direct workers, thus losing the benefit of an important resource.

The control philosophy characterising HPM leads to the redistribution of control tasks and responsibilities among process actors, and can be illustrated referring to the concept of “self-control”. Juran and Gryna [15] state that a process is in self-control when people (1) have knowledge of what they are supposed to do; (2) have knowledge of their actual performance; (3) can regulate the process, and the process can meet the specifications. When, for a certain employee, these three criteria are met as regards a specific problem, the problem is said to be worker controllable, otherwise it is said to be management controllable. In HPM firms, ideally, all the tasks assigned to each employee (from the lowest to the highest hierarchical level) should be in a state of self-control.

Consequently, the control over operational tasks carried over by direct workers should be ensured, as far as possible, by the workers themselves. Achieving this goal – for the given definition of process control – requires the modification of the information channels supporting process control in order to give each worker information on his actual performance. An important source of feedback for reaching better quality performances is information gathered from the operator himself [39,40], as happens with control charts [41]. In this way short, fast feedback loops take place, resulting in a more timely response to out-of-control situations. Another important source of feedback is information gathered by support personnel during auditing activities [42]. This information, therefore, does not only flow upwards to supervisors and managers, but even flows somewhat horizontally to support workers’ control efforts. Finally, it should not be forgotten that JIT production systems are mostly organised into lines and cells [43], in which each worker is often in direct contact with his internal customers and suppliers. This enables a horizontal information flow allowing quick
corrective action to be taken, and the establishment of what is known as an early warning system [1].

Since part of the control tasks tend to be delegated to direct workers, information flowing vertically to supervisors and managers, both for continuous process regulation and for troubleshooting, tends to diminish. In particular, information tends to be supplied in a more synthetic format, condensing only the key performance indicators and exception reporting. Superiors can then gather more detailed information directly by walking around on the shop-floor, where accurate data is shown on visual control systems conveying time-ly information on the process status and performance trends [44]. However, even if a leaner upward information flow is provided to production managers, helping them to concentrate on problems really needing their attention, the information conveyed is richer, since it pays more attention to non-financial aspects [14,45].

The concept of self-control, according to JIT and TQM, should extend upwards to suppliers, because of the high cost of quality control of incoming goods, and of the negative impact of low quality of purchased product conformance on process throughput time. However, the buyer needs evidence of the fact that these control activities are effectively carried out. An information flow supporting the surveillance of the supplier quality system is therefore needed, and it should include the status of procedures, methods, processes, products, services, etc. [15]. Moreover, information on the suppliers’ transformation processes can be directly gathered through the participation of one or more firm’s auditors in suppliers’ quality audits and system reviews [38]. Besides formal channels for exchanging control information, informal contacts between people in the buyer and supplier organisations promote better communication and a better co-ordination of the two transformation processes [1].

As regards communication with customers, the feedback on non-conformances detected by customers should be scanned in order to highlight problems that are directly traceable to the transformation process, thus triggering corrective actions. Useful customer feedback information is gathered through customer complaints, salespeople and service personnel reports, and from customer surveys. The information flows supporting the control of the transformation process in HPM can be synthetically characterised as follows:

- more timely information highlighting control problems in the plant is conveyed by means of horizontal information flows taking place between line/cell workers, and by means of external information flows conveying customer feedback on non-conformities;
- more intensive bi-directional communication with suppliers conveys information on their process capability and feedback on non-conformities;
- a smaller amount of control-related information goes upwards to supervisors and managers, conveying only problems that cannot be tackled at lower hierarchical levels, reporting exceptions, and tracking the main process performance indexes, both cost and non-cost;
- all-channel (both horizontal and vertical) communication is enabled by visual control systems (charts, schemes, graphs) which are displayed on the shop floor and which indicate cell/line/department overall performance.

3.2. Information flows for process improvement

Placing a process under control does not ensure that it will be competitive in the future: ever growing competition requires the continuous gauging of process performances to higher standards [46]. HPM firms, therefore, greatly need information to help them in the identification, screening and implementation of improvement initiatives. This information differs from that supporting process control and ad hoc communication channels should be provided to convey it to the person responsible for decisions regarding the need for improvement. Whenever these channels are absent or not sufficiently developed, important opportunities for improvement can be missed, and some chronic problems that should be faced systematically would be repeatedly “fixed” without removing their root causes, with negative consequences on performances levels.
Management plays a fundamental role in selecting, formalising and directing process improvement initiatives, and for doing this it needs ideas on improvement opportunities. Different communication channels can convey information on process improvement opportunities. Audit reporting is a first means for highlighting areas of improvement, and for giving suggestions on corrective actions and their follow-up. A second source of information for improvement is routine reporting. In the case of operational reporting (for low-level managers) information should be provided with a level of detail which makes it possible to group it in terms of product, work centre, cell, line, etc., in order to discover patterns of problems that need to be solved. The strict interdependence of the firms’ transformation process to those of its suppliers means that ad hoc data on improvement opportunities for suppliers must be collected. This kind of information can be provided by formal processes such as suppliers quality audits, suppliers quality surveys, etc., but even from informal channels, such as direct peer interactions between the firm and its suppliers [1].

A third possibility consists in encouraging personnel to make suggestions on how the process could be improved [47,48], by making reference to their direct experience. In this way, the organisation can improve itself and acquire knowledge previously retained by single individuals, unleashing the asset represented by workers experience and ignored by Tayloristic management practices. For such a practice to gain success, it is not only necessary that good suggestions are followed, but also that management explains why they are rejected if this is the case. Moreover, there should be a way to direct employees’ suggestions towards organisational goals, in order to pursue improvement efforts coherent with the firm’s objectives. A stronger focus on employees’ suggestions can be obtained by communicating the firm’s strategic objectives further down the hierarchy [19,20]. Building up a working suggestion process therefore involves vertical information exchanges, both bottom-up (the suggestions themselves) and top-down (the feedback on the suggestions, and the communication of the firm’s competitive priorities).

In many cases neither management nor workers have all the knowledge necessary for finding satisfactory solutions to a certain problem. In these cases teamwork can be adopted as a way for allowing better communication to take place between people having complementary knowledge in order to solve a certain problem. Teamwork, in fact, enables a direct and effective communication between team members to take place, fostering not only the exchange of data, but even of feelings, etc., and helping in overcoming functional and hierarchic barriers [38]. Different kinds of problem-solving teams may be instituted [15], some allowing a better horizontal communication to take place between workers in the same work area, or in the same department, others promoting both horizontal and vertical communication to take place between different functional areas. Problem-solving teams can even cross company borders, promoting a more effective information exchange with other channel members during improvement efforts.

The main information flows supporting transformation process improvement in HPM can be summarised as follows:

- more intensive vertical bottom-up information flows (routine reporting information, auditing report information and suggestions on improvement opportunities identified by direct workers) help managers in individuating opportunities for improvement;
- leaner vertical information flows convey orders, directives, and feedback information on the state of improvement initiatives, because of the greater reliance upon teamwork for problem solving;
- more intensive horizontal and, in certain cases, even vertical communication between members of improvement teams links different kinds of knowledge for problem solving;
- more external information is exchanged with suppliers for identifying and pursuing improvement, for example, involving suppliers in quality project teams;
- improvement efforts are focused by means of top down communication on the firm’s competitive priorities involving all hierarchic levels.
4. Logistics process

The logistics process plays an important role in achieving higher operating performances. In fact, (1) logistics costs represent a significant portion of total costs incurred by many companies [49], (2) speeding up the flow of goods through the pipeline is fundamental for quickening the response to market demand, (3) even some quality aspects, like product deterioration due to long storage time or improper handling, are affected.

Many actors belonging to different business areas (manufacturing, purchasing, marketing, sales and distribution) and to customer and supplier organisations, share responsibilities concerning the flow of materials in the logistics channel. Therefore, ensuring high service levels at an economic cost involves a great deal of co-ordination among these actors. A proper articulation of the logistics process communication network can be a critical means for ensuring such a co-ordination to take place and consequently to enhance logistics performances.

4.1. Information for flow planning

In HPM logistics, shorter throughput times and lower inventory levels are pursued through the synchronisation of all the elements in the supply chain and through flow stabilisation [50,51]. These goals cannot be met without proper planning, in which the various decision-makers interact to co-ordinate with each other in order to achieve logistics objectives on the basis of the information available on final demand [52].

Realising an efficient material flow imposes to maintain low inventory levels, and to shift towards more repetitive manufacturing environments [1,2] – inherently less flexible than the non-repetitive ones – thus exposing HPM firms to higher stock-out risks when actual demand differs significantly from planned demand. For this reason, the availability of reliable market information on future demand, a basic input for effective flow planning, is a primary requisite for HPM firms. Since forecast accuracy can be improved only up to a certain point, HPM firms tend to develop closer links with customers, thus pursuing the goal of flow stabilisation through demand management efforts [2,19,20,53]. These efforts, i.e. open-order agreements, or demand control actions based upon detailed customer information previously gathered, impose the development of bi-directional information flows with customers. Moreover, for earning the full potential of reliable market information on future demand, it is of paramount importance to let it flow undistorted from marketing/sales to all decision makers, both inside the company and to its suppliers [54]. In other words, instead of letting information on future demand flow backwards down the pipeline in a serial fashion by means of orders, HPM firms give contemporarily visibility on demand information to the key chain decision-makers upwards. In this way they can reduce time lags and information distortions due to conflicting functional objectives, thus avoiding flow irregularities and excessive inventory levels, and therefore poor customer service and high working capital costs.

Achieving higher process performances through better planning means that planners must be provided with information aimed at depicting logistics process capability, rather than only its performance. A primary use of this information is to provide a clear, objective basis upon which to build the unavoidable trade-off decisions peculiar to logistics management [55,56]. For example, when executing flow planning for a certain product–market combination, decision-makers need information allowing them to understand how costs are generated as the goods flow across different part of the business [54]. Information on the logistic process capability is gathered both through logistics periodic auditing and routine reporting, and it is aimed at giving a “big picture of the process”, helping decision-makers to understand how better logistics performances can be achieved [57]. However, timely process performance information (inventory holding, supply delivery performance, customer service achievements, external logistics providers achievements, etc.) is still needed by decision-makers, in order to get feedback on the actual flow compared to what has been planned, and to give input to new planning activities [57,58]. Top-down information on logistics plans is usually conveyed through structured, formalised means, like computer-based manufacturing and distribution.
planning applications, documents, etc. The trend towards delegating short-term planning (final operations scheduling) to lower hierarchical levels (supervisors) reduces both the need for detailed process reporting and for transmitting downwards detailed planning information [44].

The horizontal dimension of the communication pattern supporting the co-ordination of logistics planning activities highlights the importance of cross-functional communication between decision-makers belonging to different organisational units and involved in the same planning cycle (long-, middle- and short-term planning) [57]. The need for such co-ordination does not end at the company’s boundaries, but involves suppliers too, since in order to reach high delivery performances they need to come to some form of agreement with the firm on middle term supply volumes, mix, etc. [19,20]. Finally, the development of stable external communication channels with logistics suppliers is becoming more and more important if flow performances have to be enhanced, since external logistics suppliers are playing a growing role [59].

The main information flows supporting flow planning in HPM can be summarised as follows:

- more reliable information on future market demand is gathered through stronger, bi-directional communication with customers and immediately diffused throughout the chain by means of horizontal (interfunctional) and external communication channels;
- information for the co-ordination of the various planning cycles is ensured through leaner bottom-up communication monitoring process achievements v.s plans, and leaner top-down communication for transmitting logistics plans to the lower hierarchical levels;
- sounder decision-making in each planning cycle involves all three dimensions of information flows: bottom up information on process capability, and intensive communication, both horizontal and external, between decision-makers.

4.2. Information for flow control

By flow control here are intended all the activities aimed at putting logistics plans into practice, and at ensuring that plans are respected. The pressure for reducing logistics costs and for shortening throughput times requires the development of leaner process control structures, which run faster and consume fewer resources. Information offers a great leverage for pursuing these goals [54]. As regards this, Hoekstra and Romme [52] state that the communication pattern supporting flow control is strictly dependant upon the form in which goods move physically through the various parts of the organisation from initial supplier to ultimate buyer. Complex physical flow patterns can be seen in terms of the barriers the flow must cross (demarcation lines), where it stops (stock points) and where mixed flows (function oriented/process oriented/shared resources) occur. Complex physical flow patterns, involving the multiplication of information flows needed to keep track and co-ordinate physical flow, necessarily lead to complex communication structures [58].

Two main inputs for the control of the subprocess can be identified: information triggering order-driven logistics activities, and information triggering forecast-driven logistics activities. Forecast-driven activities are necessarily started by means of top-down communications which convey detailed planning information, while order-driven activities are, by definition, started by external information coming from customers [58]. Feeding the control process with a quick, “lean” input, which can instantly be translated into action, is an effective way to compress the process response times. In practice, the volume of detailed planning information is reduced in cell/line-based manufacturing systems [1,44], while the speed at which customer order information is gathered is enhanced through the use, for example, of EDI links [55].

The timely execution of plans and short customer order transmittal times do not guarantee that an effective co-ordination takes place between various logistic actors, both inside and outside the firm. Effective communication, both horizontal and with suppliers, is a primary instrument for achieving a co-ordinated response to actual market requirements.

External communication with customers can effectively help in co-ordinating the flow of materials and components in the context of previous
agreements, thus avoiding poor delivery performance [60]. A key information allowing a better flow management, and therefore an efficient response to the market, is that one generated on the final point of sale on the supply chain. Mason-Jones and Towill [61] refer to “information enrichment” in the order cycle activities as the practice of using “sales market information”, instead of “customer order information” to make order-related decisions. Their experimental data show that the information enrichment level positively impacts various logistics performance indexes, among which the number of stock turns, the degree of order amplification effect and the JIT capacity level. However, in order for information enrichment to convey these results it is needed that this principle is applied at the whole supply chain level. This implies that the firm should not only try to access final market order information, but it should transfer this information to its suppliers as well [61].

Internal communication for co-ordinating the flow of parts and sub-assemblies in the manufacturing area takes place through direct interaction of workers in the same line/cell, and through visual control system and, when applicable, through kanban cards, according to the JIT philosophy [43]. Finally, communication between the various actors responsible for order-cycle activities, often spread across different departments (marketing and sales, distribution, accounting, and manufacturing) is crucial [57]. Hence, HPM firms face the problem of developing ways for allowing such an intensive horizontal and external communication to take place. As regards this, multiple approaches can be adopted, based both upon IT applications [16,62] and teamwork [54,63].

Building up a lean flow control system which employs the organisation’s human assets better has heavy consequences on the information flows ensuring process monitoring. Much operating information is gathered directly and employed at the lower hierarchical levels, thus realising short feedback cycles and therefore less variance in the flow. In fact, shorter time lags between performance detection and corrective action lead to shorter response times and smoother transient oscillations of process variables [56], which in turn translates into less waste (i.e. inventory) and shorter lead times. Control-related information flowing at higher hierarchical levels concerns mainly some critical process operational variables, and problems that cannot be tackled at the bottom line. This is the case, for example, of unexpected events like serious errors in demand forecasts, and therefore in planning, that overcome the maximum variability allowed by the logistic process, and therefore call for re-planning at higher hierarchical levels.

The main information flows supporting flow control in HPM can be summarised as follows:

- leaner top-down communication conveying detailed plans and quicker external communication from customers trigger, respectively, forecast-driven and order-driven operational activities;
- quick transmission of information on actual demand and feedback for flow co-ordination are ensured through more intensive communication both inside the firm and with its suppliers;
- performance and status tracing information is collected and used mainly at lower hierarchical levels, while it flows upwards to managers only in concise reports;
- vertical information flows in support of trouble-shooting lose part of their importance, because of the great control capabilities of the bottom line and of the improved planning effectiveness.

5. Product development process

In HPM more and more emphasis should be given to the importance of improving the development process because of the direct impact it has on design quality and time to market. There is even a growing awareness of the great leverage design can offer for improving the transformation and logistics processes performances [64].

Since the product development process primary input, work-in-progress, and output is information, improving the way information circulates among process actors can help in achieving higher process performance levels. This section considers the main information flows needed for a better information sharing and delivery in the product development process.
5.1. Information flows for better designed quality

For a long time the importance of reducing the inherent complexity of development work has prevailed over the need for co-ordinating people involved in product development [65]. This led to the so-called “sequential approach” [3] which essentially consists in splitting product development projects in sequences of phases independently carried on by different departments and co-ordinated through formal project reviews and hierarchical control [65]. In sequential product development, information flowing among domain experts in a serial fashion results in poor communication [66]. Inadequate communication between phases leads (1) to the loss of abstract information, affecting the consistency of the product concept as the product specification is passed down the development chain, and (2) to the loss of optimisation opportunities, leading, for example, to low product performance, low manufacturability, etc. [67]. Achieving better process co-ordination therefore is a “must” for improving designed quality.

Information on the quality level expected by customers can be gathered by means of different channels: marketing research, field service personnel feedback, sales personnel, direct involvement of the customer in the specification setting process, etc. In order to make this information effectively available to all people involved in the specifications setting activity, some mechanisms ensuring its sharing (i.e. ad hoc meetings) or its delivery (i.e. company databases containing data on expected quality) have to be provided.

Accurate customer information does not guarantee that sound specifications are written. More intensive horizontal communication between departments and, often, external communication with suppliers are needed to foster key players commitment, to identify crucial benefits and to promote consensus reaching on design trade-offs [68]. A major challenge for HPM firms is to overcome marketing-engineering and more in general inter-functional-communication barriers relating to different thought worlds, languages, task priorities, responsibilities and physical barriers like geographic distance [69,70]. A way to get over this problem is to gather all the people involved in specifications setting in off-site workshops where the specifications are written jointly, allowing communication to take place simultaneously rather than through sequential information exchange on specifications between departments [68,65]. Quality function deployment is another possibility. This is a set of planning and communication routines that helps in translating customer requirements into engineering and manufacturing specifications [71].

Interfunctional communication does not only improve specification setting, but it also drives design activities towards more successful products too [70,72,73]. At this regard, Voss and Winch [74] point out that “increasingly, the successful firms in many market sectors are introducing close coupling between engineering and manufacturing” (p. 83). The main purpose of information exchange in this context is to prevent one product facet being defined at a time, without sufficient information on how this choice impacts on product performance as a whole. This means, for example, that product designers, not being aware of cost information owned by manufacturing experts, cannot effectively pursue cost reduction goals. Different approaches to the enhancement of both internal and external communication in design phases can be followed, depending on the complexity and expected performances of the product development process [75]. Electronic communications [75] and formal integrative management processes [76] are ways out of this problem only in conditions of low-task uncertainty. Achieving high product development performances in more turbulent environments requires a more intensive communication [75], that can be obtained through development teams’ personnel co-location [77,78], human movement between different functions [79,80], and informal social systems [81,82].

HPM firms’ efforts to promote integration through direct horizontal communication impact on vertical communication between managers and field experts. Management, in fact, partially looses its co-ordinating function, since information directly crosses departmental boundaries, following the shortest way to connect the person who owns it and the person who needs it. However, Clark and Fujimoto [12] notice that managers still hold
a co-ordination role and that not all information can be directly transferred among team members. For example, the team leader, and managers in general, can ensure the product concept consistency throughout the process and time by acting as concept infusers, keeping the project people’s work focused on the original product concept. Therefore, HPM firms tend to pursue co-ordination through vertical information flows mainly when the information exchange involves a greater level of abstraction than would be possible with day-to-day work-related communication between employees [9]. Moreover, two-step communications can take place by means of project leaders, thus overcoming language barriers between developers and keeping closer links with customers and suppliers [4,68].

The main information flows aimed at achieving a higher designed quality in HPM can be summarised as follows:

- external information on customer requirements is gathered by means of multiple communication channels and conveyed to all people involved in the early phases of product design throughout the organisation;
- simultaneous, but not sequential, horizontal and external communication between marketing, engineering, manufacturing and suppliers promotes stronger commitment and consensus reaching on specification setting;
- interdepartmental communication for design-related decision-making is mainly ensured through direct, even informal, interaction of domain experts, resorting to two-step communication through managers mainly for overcoming language barriers or for allowing non-operational communication to take place.

5.2. Information flows for reducing time to market

As time performances are becoming more and more important in product development, HPM firms have to find ways to compress the time they take to deliver new products to the market. The tools for improving co-ordination described above can help in cutting time to market, for example by reducing “scrap and rework” in development activities. Anyway, techniques which deal more directly with time-compression issues in product development are needed, and are usually labelled as concurrent engineering, phase overlapping, parallel engineering, etc. [83].

Clark and Fujimoto [84,9] have directly addressed the problem of studying how communication can shorten time-to-market. They build their model starting from the consideration that the development process can be viewed as a chain of inter-related problem-solving cycles. The simultaneous performing of these cycles is a primary means for compressing product development time. In any case, downward activities cannot be performed simultaneously without proper information coming from upwards activities; intensive horizontal communication is definitively a prerequisite for achieving overlapped problem solving. Communication for time compression can be achieved, in general terms, through higher frequency of information transmission, bilateral communication, early release of incomplete or preliminary information from upstream activities, richer information media with respect to specs and blueprints [84]. This kind of information exchange can be supported both by formal (task-forces, liaison roles, project teams, electronic links) and informal (mainly personal contacts taking place at the working level) means. It should finally be noticed that there are situations in which uncertain and incomplete information may have a dysfunctional effect on project performance. This happens in particular when downstream activities are particularly sensitive to upstream changes, and when upstream information evolution from low to high uncertainty is slow [85,86].

The main information flows aimed at achieving shorter times to market can be summarised in HPM as follows:

- information from the upwards to the downwards phase conveys loose specifications and gives information concerning the completion of upwards activities;
- information from the downwards to the upwards phase gives feedback on the impact of upwards decisions on downstream activities and provides suggestions on alternative solutions.
5.3. Information flows for development process control

The communication pattern supporting development process control in HPM should protect the firm from the inherent uncertainty of many design activities, while at the same time it should not be too complex, slowing down development work. The simplification of the information flows supporting control, together with the improved integration of development activities [87], is a major benefit in the implementation of product development teams. Reductions in reporting information on the status of the various projects, which risk slowing down the project, are primarily obtained effectively structuring the team and its task, that is to say effectively staffing the team and defining specifications [68]. The team is directly responsible for gathering, processing and using information on product and process development status, in order to meet the time, quality, and cost targets [65]. Control is, therefore, pursued by means of horizontal communication too. Vertical information flows still play an important role in ensuring proper control, but they have undergone some changes. In fact, while the importance of informal communication between team leader and other team members grows, the use of formal reporting is restricted to some critical points of the process. This is the case, for example, of the formal project reviews, in which the management gather critical information on the project in order to make a go-not-go decision and an additional funding approval.

HPM firms strive to simplify the development control communication pattern by means of other initiatives. For example, the management of product architecture (through modularization or platform development), which is important for simplifying product development [88] and logistics management [58], makes it possible to structure development work in more manageable sub-processes with less complex tasks. This implies that development tasks that can be effectively carried on independently, thus minimising risks and the need for strict control. Consequently, vertical communication for operational control tends to shrink.

The main information flows aimed at ensuring product development process control in HPM can be summarised as follows:

- vertical information flows supporting formal managerial control tend to diminish, due to the increased capacity of teams to directly gather and use information on project status to meet the assigned goals;
- vertical information flows supporting control are integrated into the project team by means of informal communication with the team leader;
- horizontal communication aimed at ensuring a common awareness of project status is achieved by means of a set of project measures synthetically depicting development performance.

6. Conclusions

In this paper a framework for analysing the communication system of a manufacturing firm has been developed. In particular, this framework has been employed to identify the specific information flows supporting high-performance manufacturing practices in three “fundamental” operating processes. The theoretical considerations articulated in this paper have implications both for practitioners and for researchers.

6.1. Implications for practitioners

The framework can be used by practitioners as a tool for addressing in a comprehensive way the problem of information delivery and exchange in a manufacturing firm. This is because the framework does not distinguish between formal and informal information flows, and can be applied regardless of the communication media adopted. Moreover, as the framework is based upon the concept of the operating process, it can guide the development of communication networks directly supporting the integration of activities conceptually belonging to the same process. Some of the most relevant practical implications are that:

- The framework directly links information flows with operating performances. In fact, it helps in relating the informational requirements of high-performance manufacturing practices to the
performances directly affected by each practice. In this way it is possible, for example, to prioritise actions aimed at enhancing organisational communication, in-line with the firm’s objectives. Improvement efforts both at the information media level (paper, telephone, computer-based communications, etc.) and at the level of the organisational arrangements supporting those media (communications taking place by means of teamwork, of visual performance indicators on the shop floor, etc.) can, in other words, be linked directly with operating performances;

- Guidance is given for identifying the most significant information flow classes. Empirical research [89] shows that hundreds of different information flows can be identified in a single organisation. As it is difficult to evaluate them one by one, a way for grouping them into some significant classes is needed. The paper provides a criterion (see next paragraph) for clustering information flows into a meaningful pattern based upon the information requirements of HPM practices.

- The business communication system has to be considered as a means through which operating performances can be directly improved. Hence not only information – as it has been claimed for many years – but even the network of a firm’s communication channels have to be considered as critical assets that must be developed if higher performances are to be pursued. This message is in line with the great amount of resources many firms are investing in enterprise resource planning systems. The successful adoption of such systems, in fact, requires the firm to develop a global understanding of the communication structure needed to support its business processes [90].

6.2. Implications for researchers

From the theoretical point of view, the main achievement of the paper is that it applies concepts developed by organisational science research to operations management, in order to contribute to understanding how the operating practices gathered under the label of HPM are associated with the way information circulates inside the firm. Even information systems literature makes use of concepts such as that of “information flow”, but often with the more limited scope of determining the better technology to support it, and, more important, without systematically addressing the problem of how information supports operations. The above considerations on the information flows distinguishing HPM firms from the “traditional” ones can be condensed into some final observations. In doing so, information flows have been clustered into three classes: horizontal, vertical and external, thus emphasising internal communication crossing hierarchy lines, superior–subordinate communication, firm–supplier and firm–customer communication.

- Horizontal information flows tend to become more important. This can be traced back to different causes. Firstly, horizontal communication supports the co-ordination of process activities better than vertical two-step communication involving managers as “information bridges” between people in different parts of the organisation. In fact, horizontal communication offers the shorter way to connect the person who owns and the person who needs operational information, and shorter communication channels cut time lags and errors in information exchange. Secondly, horizontal communication makes possible the simultaneous sharing of knowledge held by people in different parts of the organisation, thus unleashing a great potential for improvement. In fact, the interaction of properly trained and empowered employees, for example in the shop floor or in design facilities, often goes beyond the co-ordination objective, enabling the exchange of expertise for improvement and problem-solving.

- Vertical information flows tend to change in purpose and content. One of the main consequences of the trend towards delegating to the lower hierarchical levels tasks previously retained by managers is the shrinking of vertical information flows supporting (1) process monitoring; (2) troubleshooting and problem-solving more in general, and (3) co-ordination. The managers’ need for process monitoring information is reduced because of the greater training and empowerment of personnel, which give them the
means for – at least partially – controlling their work. Vertical information flows supporting troubleshooting and problem-solving tend to shrink for the same reason: front line personnel is more capable of facing and solving problems, or at least need a less strong support when facing problems. Last, co-ordination tends to be achieved through direct interaction of people, for example in teams, instead of having higher level managers to work as information bridges between departments. All this does not imply that vertical communication channels loose their importance. Rather, the information they convey is less operational, more oriented towards giving managers the overall picture of the activities put under their responsibility, and promoting a continuous process improvement and adjustment to environmental and competitive needs. This trend is reflected, for example, in the less detailed but multidimensional report information provided for managers, or in the bi-directional vertical information exchange that permits a dialogue to take place between workers and managers on improvement initiatives.

- **External information flows** tend to play an increasingly important role. HPM firms differ from the others in the way they exchange and use customer information. First, there is a growing awareness that customer information is the key for linking the firm’s operating activities to the market. As a consequence, there is a deliberate effort to promptly transfer this information to all relevant actors both within the firm and outside the firm along the supply chain. Second, the need for the firm to attempt to condition its environment is mirrored in a greater bi-directionality of information flows involving customers. These information exchanges are aimed, for example, at stabilising demand and reducing its uncertainty, or at improving quality. Third, external communication with suppliers can be often viewed as a means for better co-ordinating processes and activities that depend on different organisations, but are strictly intertwined. Moreover, these information exchanges can foster the sharing of knowledge between the firm and its suppliers, thus supporting improvement and problem solving.

As these conclusive considerations are the result of a theoretical construction based upon a critical review of the literature, further empirical research is needed to explore the association of information flows to process-related operating performances.

**References**


