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Supply Chain Management from a Systems Science Perspective

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1. Introduction

Supply chain management (SCM) is going to be the main management process for production systems in the xxi century. This management process will take care of the flow of materials, information, purchased parts, personnel and financial needs supplied from different vendors, sometimes geographically too far from the main production plant. The industry of domestic appliances is a good example of the supply chain management. Before SCM a production system designed their products itself and manufacture all the subassemblies and components and gave after sale service during and after warranty period. After SCM the new production systems “comakership” several aspects of the production process, for example hermetic compressors for fridges, plastic parts and motors for washing machines, electrical components, etc. SCM provides different management principles to help in the designed planning and controlling the network of suppliers in order to synchronize the variability of customer’s demand with the variability of capacity of suppliers. One management principle is called Asbhy’s law: “the variability of the manager system should be more than or equal to the variability of the managed system”.

In order to speak correctly about SCM let see how is the official definition expressed by the Association for Operations Management in their APICS Dictionary (Blackstone, 2008): SCM is “The design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging world-wide logistics, synchronizing supply with demand, and measurement performance globally”. The previous definition emphasizing the main functions of production systems management as follows: the design of the supply chain when it is going to be a new corporation, the **planning** of operational and strategic activities, the scheduling and **execution** of the production planning, the **control** and solution of conflicts and the monitoring and auditing of the production processes . The financial management to create **net value** to all stakeholders: owners , employers, employees, society and environment. In the following section of this chapter, it is going to be described in more detail each one of the manufacturing functions of Supply Chain (SC), considering a systems approach based on the five components of the Viable System Model (VSM) by Beer (1985). Supported by the popular business/industrial information system called Enterprise Resources Planning (ERP).

After the theoretical description of the SCM via a systemic approach, it will be presented an application of fractal theory to improve inventory management synchronization of supply with demand considering a frequent phenomenon in sequential processes of SCM, called bullwhip effect. The financial management to create net value to all stakeholders: owners, employees, society and environment. An actual example of SCM implementation was reported by Proctor (2010) in the case Dupont, a multinational company with headquarters in Willington, Delaware. The company has operations in more than 70 countries and diverse product lines including agriculture, nutrition, electronics, communications, home products, etc. DuPont managers "credit the corporate survival and success during the recession to their employees' strong SCM knowledge which has given them visibility across business units. DuPont started in this area with kaisen, Lean and Six sigma. Once low cost sourcing was added SCM was a natural segue" (Proctor, 2010:12). Dupont management started to rely on demand planning (Customer Relationship Management, CRM), raw-material planning (Material Requirement Planning, MRP), finish-to-stock (FTS), package-to-order (PTO) and make-to-order (MTO) strategies, tightened delivered schedules (Master Production Schedule, MPS) logistic flexibility (Distribution Requirement Planning DRP) and effective sales and operation planning (S&OP); all of this functions belong to the management of SCM via ERP. In this chapter it is used the terms Manufacturing Systems and Production Systems as synonymous.

2. Systems Science

In order to be in accordance with the title of this chapter, it is convenient to define some systems concepts:

Environment. The context within which a system exists, includes everything that may affect the system and may be affected by it at any given time.

Function. Denotes actions that have to be carried out in order to meet system's requirement and attain the purposes of the system.

General System Theory. The concepts, principles and models that are common to all kinds of systems and isomorphism among various types of systems.

Human activity system. A system with purpose, that expresses some human activities of definite purpose; the activities belong to the real world.

Model building. A disciplined inquiry by means of which a conceptual (abstract) system's representation is constructed or an expected outcome/output representation is portrayed. There are models of function structure (like a still picture) and models of processes (like a motion picture).

Subsystem. A greater system's component, is made up of two or more interacting and interdependent components. The subsystems of a system interact in order to attain their own purpose(s) and the purpose(s) of the systems in which they are embedded.

System. A group of interacting components that keep some identifiable set of relationships with the sum of their components in addition to relationships (i.e. the systems themselves) to other entities.

Systems Science. The field of scientific inquiry whose objects of study are systems (Klir, 1993:27 in Francoise, 2004) and its structure is composed of a domain, concepts, theories and methodologies.

Variety. Number of possible states that a system is capable of exhibiting (Beer, 1979).

Viable System Model (VSM). It is a system able to maintain a separate existence, capable of maintaining its identity and transcend independently.

The System Science use the constructions of models to represents real systems, for example the Viable System Model (VSM) was elaborated by Beer (1979) to represent manufacturing/productions systems like the SCM.

The VSM presents a new way of looking at an organizational structure. It is a recursive model in which each successive unit is nested within the next larger one. It is a pre- eminent way to manage variety. It is a logical structure which differs from a classical hierarchical organizational chart but helps management to organize effectively the Production System. According to the VSM in any viable system, there are five systems interactively involved in any organization that is capable of maintaining its identity and transcend independently of other organizations within a shared environment (Beer, 1989). If an organization survives in a particular sort of environment, it is viable. All manufacturing systems are embedded in a continuously changing environment of socio-political World Economy. Success in global and local markets with social satisfaction requires constant unrelenting efforts to develop more viable manufacturing systems, aware of quality and sustainability. The VSM is organized on five subsystems/elements that in this chapter are designed as 1) operations management, 2) coordination, 3) auditing/monitoring, production management, 4) general management, and 5) board of directors. In a VSM, System 4 is concerned with the future (the outside and then: Budget of long range forecast and marketing) as opposed to system three's concern with the present (inside and now: the best integration and coordination of existing resources. production logistic such as master production schedule, resources requirement planning, materials & capacity). Sales and operation management (S&OP) is a typical system one function managed by System 3, monitored by System 3 (auditing/monitoring) and coordinated (avoiding conflicts) by System 2.

In order to interconnect the five subsystems of VSM, it is necessary to add an integrated information system like Enterprise Resources Planning Systems (ERP). The ERP have received considerable attention recently, not only in the management of manufacturing industry but also within the services industries and their financial management. The VSM is recursive and ERP supports the management of each recursion. For example, in each component of SC there are 5 recursions levels, starting from Warehouse Management (WM) to Material Requirement Planning (MRP), to Manufactory Requirement Planning (MRPII), to Enterprise Resources Planning (ERP), and to Supply Chain Management (SCM). In each recursion level, there are emergent properties like the two categories of demand: independent demand and dependent demand in MRP; the feedbacks in the closed cycles in MRPII; the local, future and total environments, the interactions between the market and the Production System in ERP and the Law of requisite variety helps to manage complexity of SCM.

3. The Viable System Model: Description

Human organizations are much more complex than we are usually prepared to admit. Organization charts do not show how the organization really works, and in fact, real-world systems have variety which is effectively mathematically infinite. Consider the system as a traditional production model in fig. 2. The Operation is the element which does things. The Management is the element which controls the doers. And the Environment is the surroundings in which they function. The variety in the surrounding Environment will always be greater than that in the Operation, which in turn will be greater than that in the

Management of the Operation. In order to cope with its environment, the Operation needs to match its variety to that of the Environment. In order to manage the Operation, Management needs to match its variety to that of the Operation. The Operation can cope with its Environment, as long as it can successfully absorb the variety from it, by attenuating the incoming variety, and amplifying its own variety back to it. Likewise, Management can cope with the Operation as long as it can successfully absorb the variety from it, by attenuating the incoming variety, and amplifying its own variety back to it. Here it is very important to take into account the Ashby's Law of Requisite Variety, which stated that control can be obtained only if the variety of the controller is at least as great as the variety of the situation to be controlled (Ashby, 1957). If these requirements are met, the system can maintain itself in a state of dynamic equilibrium, which is called self-organized system. If these requirements are not met, the system will become unstable and eventually leading to its collapse.

What persists in self-organized systems is the relationship between the components, not the components themselves. They have the ability to continuously re-create themselves, while being recognizably the same. This ability to maintain identity is related to the fact that these systems have purposes. These purposes provide the framework for their maintenance of identity.

The Viable System Model (VSM) claims to reveal the underlying structures necessary for a system to meet the criterion of viability. The VSM methodology was developed by the cybernetician Stafford Beer (Beer, 1972). The criteria of viability require that organizations are or become ultra stable, i.e. capable of adapting appropriately to their chosen environment, or adapting their environment to suit themselves. The VSM models the structures of the organization and the relationships between them. This includes key processes, communications, and information flows. The VSM has been used as a diagnostic tool in different contexts (Espejo & Harnden, 1989). Not only in the management of the manufacturing industry e.g. the explanation of the general production management model of the Enterprise Resources Planning Systems (Tejeida *et al.*, 2010), but also in the financial management and in the service industry. The model is composed of five interacting subsystems. Kinloch *et al.*, (2009) states in summary, that systems 1-3 are concerned with the "here and now" of the organization's operation, system 4 is concerned with the "there and then" - strategical responses to the effect of external, environmental and future demands of the organization and system 5 is concerned with identity, values, mission and policies directives which keep the organization as a viable entity.

Briefly: System 1 Produces the system refers to the fundamental operations within a viable system which enclosed several primary activities. Each primary activity is itself a VSM. System 2 consists of a regulatory center for each element of system 1 and allows system 3 to monitor and coordinate the activities of system 1.

System 3 is responsible for system 1 control and provides an interface with Systems 4/5. System 3* has an audit function to monitor various aspects of the accountability relationship between System 3 and System 1. System 3* might assure that the quality of service, safety standards, financial information, internal control, etc are in order. System 4 has the purpose to look outwards to the environment to monitor how the organization needs to adapt to remain viable and need a feed back through system 3. Strategic Planning plays a big roll into this system to pursue a well connection between System 5 and System 3. System 5 is responsible for policy decisions. The former role effectively defines the identity and ethos of the organization - its personality and purpose.

In addition to the subsystems, there are some principles to make the system viable (Beer, 1979): a) Managerial, operational and environmental varieties diffusing through an institutional system tend to equate; they should be designed to do so with minimum

damage to people and cost. b) The four directional channels carrying information between the management unit, the operation, and the environment must each have a higher capacity to transmit a given amount of information relevant to variety selection in a given time than the originating subsystem has to generate it in that time. c) Wherever the information carried on a channel capable of distinguishing a given variety crosses a boundary, it undergoes transduction; the variety of the transducer must be at least equivalent to the variety of the channel. d) The operation of the first three principles must be cyclically maintained through time without hiatus or lags.

3.1 Modeling a general SCM with VSM and ERP

In fig. 1. it is presented an SCM according to the VSM interconnected with ERP

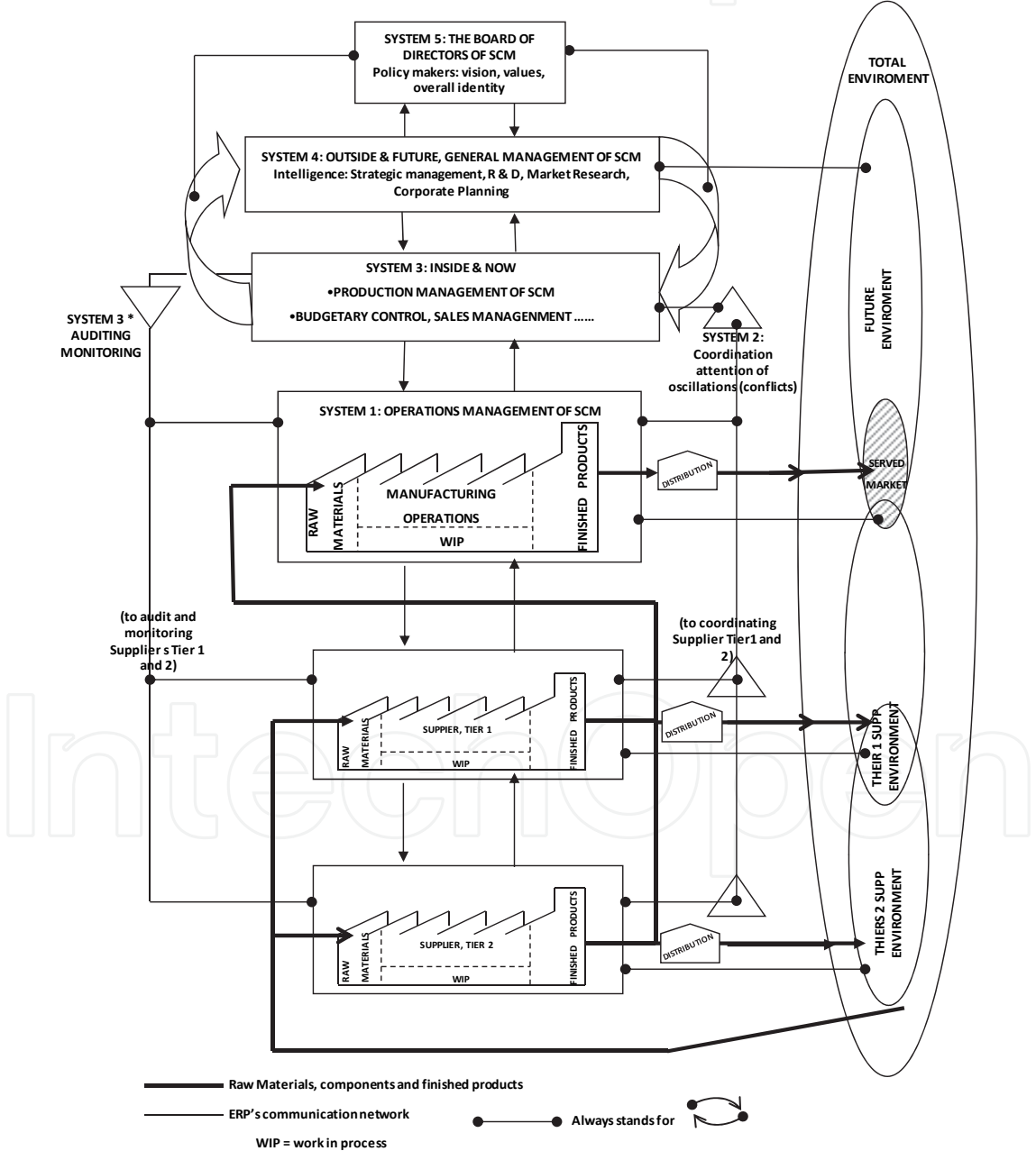


Fig. 1. A General Supply Chain Management Model based on VSM.

System 1: The System 1 of a production system produces the system and consists of the various components directly concerned with carrying out the tasks that the production in a system is supposed to be doing, such as the tasks performed by some of the following ERP modules (See Table 1).

Each manufacturing department and or supplier is connected to the wider management system by the vertical communication channels to receive instructions and to report performance, preferable on standard electronic screens to manage variety. In order to be viable systems each manufacturing department or supplier should be autonomous and be able to make its own decisions according to the Master Production Schedule (MPS), shared thru ERP. The multiuser ERP system helps to reduce the bullwhip effect.

System 2: This system has a coordination function whose main task is to assure that the various manufacturing departments and or suppliers of a production system act in harmony, damping their oscillations so that common resources and support services are run smoothly avoiding the archetypical situation know as the “tragedy of the commons”. Decisions of System 2 are based on what is best for the whole which is often different from the best for a particular manufacturing department (Leonard, 2008). It is the System 2’s job to oversee the interaction between departments and to stabilize the situation to obtain a balance response from system 1. Normally this coordination function is located inside the Manufacturing Engineering office and uses some modules of ERP (see Table 2).

1. Sales and operation management (SOP) to develop tactical and strategical plans to achieve competitive advantage	2. Customer Relationship Management (CRM) to understand and support existing and potential customers needs
3. Quality Function Deployment (QFD) to ensure that all major requirements of the “voice of the customer” are incorporated in the product or service	4. Master Production Schedule (MPS) to reflect the anticipated production schudule
5. Material Requirement Planning (MRP) and informatics algorithm that processes data from BOM, IM and MPS	6. Capacity Requirement Planning (CRP) to determine in detail the amount of labor and machine resources required to accomplish the MPS
7. Bill of Material (BOM), a file of the product structure	8. Bill of Processes (BOP)
9. Shop floor Control (SFC)	10. Production Activity Control (PAC)
11. Suppliers Relationship Management (SRM)	12. Total Quality Control (TQM)
13. Maintenance Management (MM)	13 Distribution Requirement Planning (DRP)

Table 1. ERP’s Modules for System 1 of VSM.

- Production Scheduling (MPS)	- Quality control of major Raw Materials
- Work procedures / Bill of processes (BOP)	- Maintenance Management (MM)
- Supply Chain Event Management (SCEM)	- Manufacturing Auditing (MA)

Table 2. ERP’s Modules for System 2 VSM.

*Systems 3 and 3**: System 3 is a command control function. It interprets policy in the light of internal data from System 2 and monitoring or auditing reports from System 3*. The task of the last one is to give system 3 direct access to the state of affairs in the operations of System 1, of each manufacturing department and or suppliers.

Through this channel, System 3 can get immediate information, rather than hinged on information passed to it by the localized management of manufacturing departments and or suppliers. For example to check directly on quality, maintenance procedures, employee comfort, etc.

The ERP modules that help System 3 to command and accomplish its management and control functions are shown on table 3.

From the accounting and financial perspective, there should be one of two fundamental objectives in a production system. One is to obtain the capability to produce a product or service that can be sold at a profit represented by A/R, A/P, F/A, etc. The second, is to improve an existing product or service so as to improve performance and customer acceptance, or reduce cost with the help of “Activity Basic Costs” (ABC) without sacrificing customer acceptance either of which would lead to higher profits. From the information processing point of view, the capacity of managers in System 3, of carrying out the control function, needs to be in balance with the current information flowing through the three incoming channels: 1) Coordination from system, 2) auditing / monitoring from system 3*, and 3) command from System 1.

Shop Floor Control (SFC)	Financial Business Modules like:
Manufacturing Execution System (MES) (to control and monitoring of plant-floor machines and electromechanical systems)	Activity Based Costing (ABC) to get real cost of finished products or services
Input – Output control and Production Activity Control (PAC) (to control details of production flow)	Accounts Payable (AP)
Human Resource Management (HRM) (for payroll, time management benefits administration, etc.)	Accounts Receivable (AR)
Plant and Equipment Management (FA) (Fixed assets management)	General Ledger (GL)
Shop Floor Control (SFC)	Fixed Assets (FA)
Manufacturing Execution System (MES) (to control and monitoring of plant-floor machines and electromechanical systems)	Payroll (PR) for salary administration
	Profit and cost center accounting, etc.

Table 3. ERP’s Modules for System 3 and System 3* of VSM.

Systems 2 (coordination), System 3 (monitoring) and System3 (production management)* are highly dependent on timely and accurate reporting of what is happening in System 1 (operation management, manufacturing operations and its environment). It makes no sense to install an expensive data collection subsystem of ERP if the data are not close to real time

as possible (Turbide, 2007). The big dream of accountants is not to be faced with the “month end” syndrome and real time data approach to a solution because the ERP systems are updated all the time (Currant & Keller, 1998). ERP changes the accountants’ role in System 3 because they have more time to assist management in System 3 as general advisors who can use the numbers to reduce variety and improve management of System 1. Real time data are subject to statistical filters of variety and processes to help achieving a better management of the System 1’s variety.

Real time data contribute to auditing/monitoring coordination and control of System 1 through some additional ERP’s modules and functions such as: 1)Advanced Planning System (APS), 2)Available to promise and capable to promise functions (ATP), 3)Production Activity Control (PAC), and 4)Inventory Management (IM).

System 4: System 4 performs the research and development function of a manufacturing SC system, it has two main tasks:

1. Translate Instructions and reports between System 5 Board of Directors and the lower – level systems.
2. To capture all relevant information for the production system, about its total environment.

If the manufacturing SC system is to be viable and effective it has to, somehow, match the variety of the environment in which it finds itself. To do this it must have a model of the environment that enables predictions to be made about the likely future state of the environment and allow the production system to respond in time to threats and opportunities.

System 4 is the point where internal and external information can be brought together. Activities such as Strategic Planning, Market Research, Research and Development and public relations should be located there.

The ERP modules that can help perform the tasks of system 4 are shown on table 4:

Human Resource HR	Advanced Planning System (APS)
Product Life Cycle (PLC)	Long Range Forecasts (LRF)
Legal and Fiscal Planning	Business Planning under various scenarios

Table 4. ERP’s modules for System 4 of VSM.

The data base of the Human Resources module (HR) helps to build a portfolio of human resources, evaluated with high potential, for HR Requirements planning in order to have the right managers in the right amount and in the right time.

The Advanced Planning System/Master Production Schedule (APS/MPS) are feed forward systems which processes current information of operations with future ideals and adjust the output model accordingly.

One of the most important responsibilities of system 4 is to keep adaptation mechanisms of the production systems with its future environment, represented by groups of investors, shareholders, governments, unions, communities, etc.

System 5: System 5 is responsible for the direction of the whole production system; it is where identity and coherence are focused by the board of directors. System 5 activities include formulating policy on the basis of all information passed to it by system 4 and communicating the policy downward to system 3 for implementation by the manufacturing departments and or suppliers. System 5 must ensure that the production system adapts to the external environment while maintaining an appropriate degree of internal stability. It is

the thinking part of the production system. There are no modules of ERP to help activities of system 5. It is recommended for developers of ERP systems to design modules for consensual agreements, strategies and policies based on methodologies such as Syntegrity from S. Beer, (1994) Interactive Management from J. Warfield (1994) or CogniScope from Christakis (2007) Algedonic information coming directly from system 1 to system 5 helps to manage critical situations.

4. A VSM approach for after-sales spare parts service in telecom firms

The service sector encompassed "all economic activities whose output is not a physical product or construction, is generally consumed at the time it is produced, and provides add value in forms (such as convenience, amusement, timeliness, comfort or health) that are essentially intangible concerns of its first purchaser" (Quinn *et al.*, 1987). The service industry including OEM's telecom firms plays an important role into the economic activity in any society. Fitzsimmons and Fitzsimmons (2007) stated that during the past 90 years, we have witnessed a major evolution in our society from being predominantly manufacturing-based to being predominantly service-based. Nowadays the last constitutes the new engine for global economic growth. Modern telecommunications are like a catalyst of States sustainable development: these represent a vital element to the proper functioning of enterprises, and it is part of the quotidian life of almost every individual in this planet (Kuhlman & Alonso, 2003). Into the telecom industry: repair, spare parts, installing upgrades, technical support, consulting, training, field corrective maintenance, etc., are typical after-sales services offered by the Original Equipment Manufacturer (OEM). By offering effective after sales services, the operating margin contributions outweigh the benefits of increased revenue by approximately 50% if the service is efficiently managed by the OEM, although most companies either do not know or do not care to provide after-sales service effectively (Cohen *et al.*, 2006a). What follows concern only to the level of an OEM dedicated to after sales spare-parts service.

Today, operator customers are pursuing to outsource services for a number of reasons. Of particular interest among them are: reduce capital expenditures (CAPEX) and operational expenditures (OPEX) in inventory investment and management respectively, cash flow improvements, reduced operational complexity, network availability improvements, etc. According with the consulting firm Pyramid Research (2006), 47% of the mobile Costumer Operators (CO), outsource some or all of their spare parts management activities while wireline (CO) just 21%. This represents a growing opportunity of revenue streams and profit for OEMs, but capture this profit is not easy and the OEM after-sales service parts need to face different challenges, e.g. customer needs and behavior, logistic management, budget limit, IT infrastructure, product upgrades, phase-out products support, product quality, warranties, worldwide repair vendor network, import/export processes, customer support, customer network installed base visibility, long supply and repair lead times, intermittent and probabilistic demand, integration and coordination between different echelons within the supply chain, variability across the entire supply chain, etc.

In the realm of service parts management, relationships between OEMs and CO are often established through service agreements that extend over a period of time. The details of these service agreements vary in nature depending on customer requirements, e.g. response time, customer budget, etc. Then customer concern would be high network availability and OEM challenge would be to allocate and optimize resource to commit the agreement.

The objective of this section of the chapter is to show a systemic approach to support the after-sale spare part service using the VSM methodology (Beer, 1989), involving strategy, tactical and operational aspects into an integrated manner that helps the after-sales service organization to design and operate the supply chain. The SC designed and organized according to the VSM will achieve a more effective service to profit SC due to: 1) reduced operating conflicts, 2) improvement of quality services due to better auditing and monitoring, 3) improvement of the level of service (punctuality on deliver of spare parts, opportune attention of customers claims), and 4) better management of inventory and financial information due to ERP. Section 5 describes the process concerning the spare parts service, section 6 describes the modeling of the spare parts service using the VSM, and ERP.

5. The spare parts service in OEM's telecom firms

OEM telecom firms offer different after-sales services portfolio to their customers, e.g. technical support, return for repair (RfR), advance & exchange (AE) spare parts, field corrective maintenance, etc. As stated before, OEMs and CO established the service scope through an agreement. This must clearly defined and integrated the service with tools and processes that define the technical aspects of service delivery as well as the metrics that quantify the effectiveness of the service (Hartley, 2005). Also, this must identified the product hierarchy that is going to be support by geographic region (Cohen, Agrawal and Agrawal, 2006b). The Service Level Agreement (SLA) must be attainable, affordable, and measurable and must focus on the customer's primary business (Hartley, 2005). Once negotiated, CO concern must be network availability through the SLAs, and OEMs must focus on achievable SLAs that distinguish their services from competitors.

This part of the chapter will focus only on RfR and AE services which are both related with spares. In a RfR service, the operator send a faulty part to the OEM, then the commitment is to return a good part to the operator in a contractual specified time, e.g. 30, 60 or 90 days¹. Depending on the repair cycle time² and the contractual time, the OEM needs to balance the differences between these two times through the use of a spare pool, e.g. if 30 days is contractually established and the repair cycle time is 90 days, then the OEM will need to allocate a spare pool to meet customer agreement. The repair system faces different challenges: thousands of items management, worldwide repair vendor network, operator cumulated demand³, different import / export country requirements, material handling damage risk, etc.

Regarding the AE spare parts service, consider a two-echelon distribution/repairable system as shown in fig. 2. The process is as follow: the customer requests part(s) to the OEM's call center. Then this captured the required information to properly make the delivery. The delivery might be according with the SLA, e.g. 2 hr, 4 hr, Next Business Day, etc., from an specified local warehouse (W_i) $i = 1, 2, \dots, n$ nearest to the customers. In parallel to the delivery process, the central warehouse Distribution Center (DC) replenishes the local

¹ Likewise, there are another metrics that can be measure in this process, e.g. Not Fault Found (NFF), same serial number repair rate, not repairable units rate, etc.

² This time includes the repair time and all transportations/custom times.

³ This means that the operator does not send the unit to repair once this has failed; he accumulates faulty units during a time and then sends all of them to repair. This could cause a delay delivery respond to the operator or an OEM investment in inventory to meet the contractual time.

warehouse to keep a specified inventory level. Once the customer receives from the OEM the good part, he returns a defective unit back to the OEM in an agreed (in practice it is random) number of days. Then the defective part is send to Repair Center (RC) and once repaired, the part is allocated in the pool of good units into the distribution center. When units are not repairable, these can be sent to scrap. Also when the OEM has excess inventory, this can go to the scrap process. The time elapsed since the delivery of the good unit from the OEM to the operator until the units are repaired and returned back to the inventory will be called the Turn Around Time (TAT). This includes the defective collect time and the repair cycle time⁴. Generally, the AE service is used to support critical Customer Operator customer network elements that can affect the continuity of telecommunication services.

It is very important to mention that the customer-echelon has an important role into the supply chain performance due to the service / supply process variability introduced by the customer. Basically there are two types of variability: (i) the first is related with the demand/failure parts process which includes the activities that use and thus subtract material from the warehouse inventory, (ii) the second is linked with the defective collect process, where the customer is an active participant into the TAT formula. In order to tackle the first variability, OEM uses operator installed base database and part failure rate⁵ (Trindade & Nathan, 2005; Meeker, 1998) to predict demand; the second variability reduction depends on OEM-operator's effort to return the defective units back, and it's up to them how much effort they apply to the task (see Frei (2006), who outlined strategies for managing this variability).

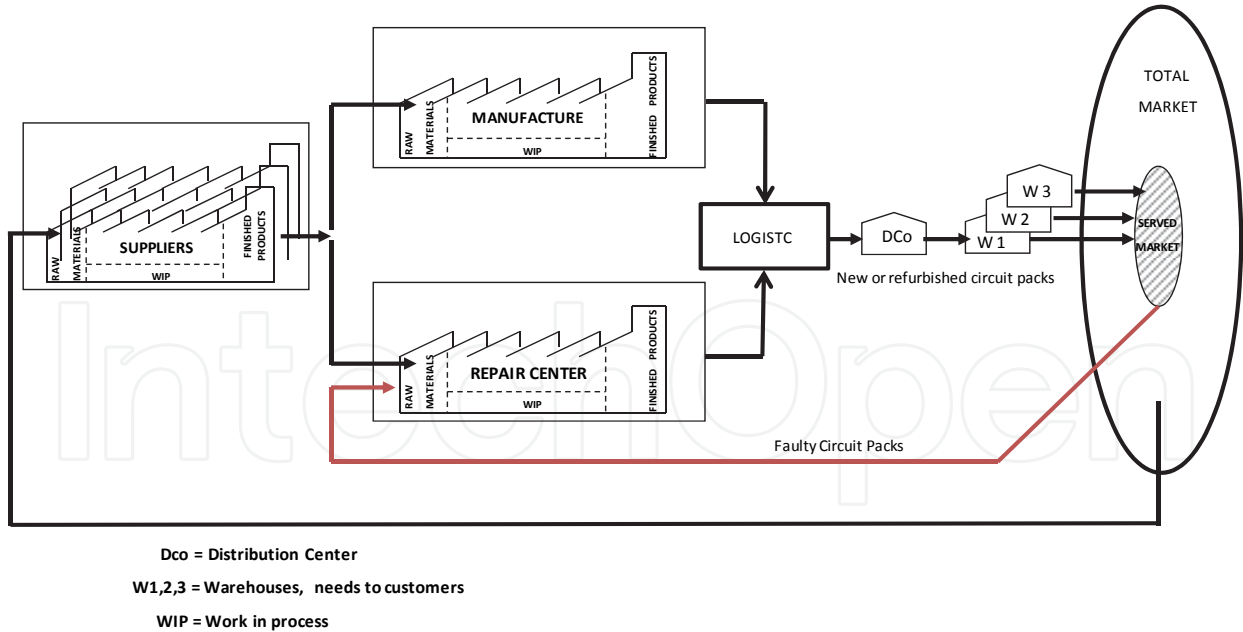


Fig. 2. Schematic of materials flow in an After-sales AE spare parts service SC.

⁴ Notice that this time is exactly the same in the RfR service.

⁵ There are two statistical tools to predict failures: Mean Time Between Failures (MTBF) for constant hazard rates or Mean Cumulative Functions (MCF) for non constant hazard rates.

6. Modelling a OEM's SC spare parts service, with VSM and ERP

Organizations need a link between the strategy and operations. OEMs compete on services but they need to make a trade-off between the service level vs costs. This trade-off can be depicted through an efficient frontier curve shown in fig. 3. This represents the most efficient (lowest cost) system for achieving a given performance level. Points below these curves are infeasible and above inefficient. Taking into account this trade-off and the VSM principles, this section will apply the VSM to the after-sales spare part organization in order to link the strategy with operations and to do the system viable.

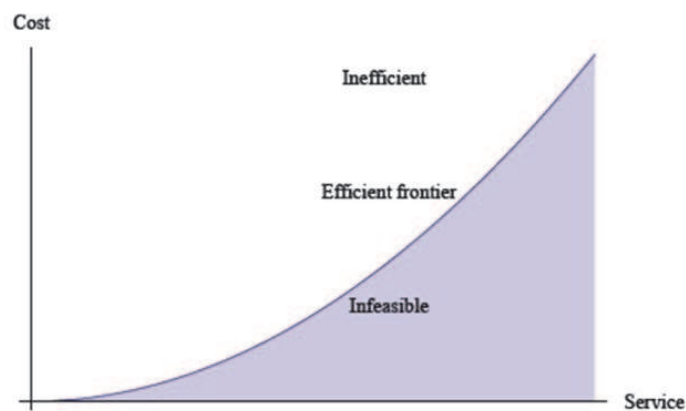


Fig. 3. Service-Cost trade-off and the efficient frontier.

6.1 System 1: Operations management OEM's SC

After-sales spare parts service operations were described at the beginning of section 5. This system encompasses all the primary activities to provide the AE & RfR services. Fig. 4 shows how the different entities are related each other. The OEM is the core operation center⁶. Basically the inputs and outputs through the supply chain are: inventory/spare parts, information and financial transactions. Considering a systemic approach, these three elements act as an interface between subsystems. The connection between the Customer Operator request and the OEM is through a Call Center with the help of a ticket system. If an AE service is required, then the Customer specifies the required part number, the delivery address, contact, phone number, etc., then the OEM must deliver the requested unit, according with the SLA, from the appropriate warehouse. The faulty unit is returned back accordingly with a contractual number of days. Once the OEM receives the faulty unit then this is sent to repair with a specific ticket number. Another activities that take place in the operations are the replenishment, rebalance, redeployment, new buys⁷ and scrap inventory transfers. All these activities are registered into the ticket system and the ERP system, and each transaction has a cost associated.

⁶ A common practice in the industry is to outsource all or part of the operation with a Third Party Logistics (3PL), e.g. warehouse and transport, and according with Simchi-Levi, Kaminsky & Simchi-Levi (2003), the 3PL relationships are true strategic alliance.

⁷ Inventory new buys as well as scrap, are not common processes, they occur occasionally. If the OEM has a shortage of inventory, then a purchase order to the manufacturer can be issued under an Estimated Time of Arrival (ETA). But this needs to be evaluated by System 3.

RfR services are slightly different from AE services with less inventory investment and less service failure risk, but use the same elements shown in fig. 4. The process begins with a repair ticket requested by the Customer Operator. Then the OEM received the faulty unit and this is sending to repair. Once repaired the unit is returned as refurbished to the Operator under a specific SLA. All transactions are registered also in the ERP system.

6.2 System 2: Coordination and anti-oscillatory actions

The supply chain⁸ shown in Fig 4 involves multiple levels and organizations. Coordinating the stocks and flows of inventory in such multilevel system is a central challenge. In order to be viable and into the efficient frontier curve (see fig. 3), the Operations need to co-operate with each other, and maintain a suitable state of balance between them. As stated by Hopp (2008) the relevant insights which are related with the inventory coordination in the supply chain are: (i) bottlenecks cause congestions, (ii) variability degrades performance, (iii) variability is worst at high utilization resources, (iv) batching causes delay, and (v) pull is more efficient than push. An interesting phenomenon that occurs in supply chains is the observed increased in demand as we travel up in the supply chain. This increase in variability is referred to as the bullwhip effect (Lee, Padmanabhan & Whang, 1997) and causes significant operational inefficiencies. Thus, it is important to identify strategies to efficiently coordinate the supply chain and cope with the bullwhip effect (see section 6). Another concern of coordination is that the flows of spare parts differ from the information flows in some ways. As stated before, the topology of the OEM, the (CO) and the Repair Centers is spread worldwide. This characteristic creates different complexities to manage the flows of spare parts and information. Spare parts flows tend to be longer to process than information flows. The former may be slower to receive and slower to process. Errors in spare parts flows may be costly and time consuming to correct (Bailey, 2008). To cope with last issues, the coordination among the (CO) and the OEM as well as between the OEM and the Repair Vendor may take place through contracts which establish and align in some manner how the units will flow in the supply chain avoiding conflicts in the use of resources.

The structure of the hierarchical organization coordinates also the task of different individuals into the supply chain. Bar-Yam (2004) mentioned that today real organizations are not pure hierarchies. They are hybrids of hierarchies and networks. There are many lateral connections corresponding to people talking to each other and deciding what to do⁹. Finally material flow into the supply chain in some degree is also data flow. This must be properly registered and coordinated into the ERP and Ticket system. Later the data needs to be converted into information in System 3.

6.3 System 3: OEM's SC management and 3* technical audit and monitoring

System 3 is occupied basically on tactical tasks related with the after-sales spare part service. The principal concerns are customers, so the KPI metric review is in the top of different management tasks. Here, on-time delivery (OTD) is the typical metric used to measure the

⁸ A supply chain is a goal oriented network of processes and stock points used to deliver goods and services to customer (see Hopp (2008)). In this case the supply chain is composed basically by the OEM the Operator and the Repair Vendor. The Manufacture is part of the supply chain just in case the OEM needs new material to buy to allocate into the stock pool.

⁹ Bar-Yam (2004) stated that if a single individual is in control of an organization, the organization is limited in complexity to the overall complexity of that single human being (in some manner, this is the same as Ashby's Law of Requisite Variety). Two ideas are illustrated by him: 1) there is a trade-off between complexity and scale, and 2) the success of the organization depends on both complexity and scale.

OEM performance. Important information to properly allocate and optimize resources is the entitlement database of each customer contract. This information is commonly used into the planning process and into the KPIs elaboration. Data analysis is also an important task to review around customer's behavior. This part of the process can be supported by a Customer Relationship Management (CRM) system.

In terms of material planning: demand analysis, TAT analysis, supply chain queue analysis, and stock optimization, are part of the analysis. This provides the basis for operations decisions in System 1 such as replenishment, rebalance, repair and defective collect priorities, new buys and scrap. All these analysis are managed by a Decision Support System (DSS).

In the supplier relationship management (SRM) system the goal is to streamline and make more effective the process between the OEM and the 3PL and the Repair Vendor. The financial management takes care of the inventory turnover metric, the gross and net inventory plan through the new buys and scrap process control and also the logistics and repair costs associated with all the customer contracts.

System 3* Audit allows System 3 Management to be in directly contact with operations. This provides a feedback loop which creates a continuous improvement environment. Once System 3 received all the information and, based on System 4 guideline, it established the critical success factors (CSFs) which will ensure the success of the services and establish the Master Operation Plan.

System 3 knows that sales forecast and other variables are always wrong. Following (Schlegel and Murray, 2010), Sales and Operations Planning (S&OP) is where team members of systems 1, 2 and 3 achieve consensus to operationalize strategies of system 4, corporate policies of System 5 and start scenarios planning, using data from ERP systems to identify historical behavior and uncertainties of all relevant factors, including: lead times, capacities, demand levels, productions schedules etc.

In section 7 of this chapter, we apply the fractal theory to characterize the number of failures of telecom cards in order to improve inventory management of spare parts considering bullwhip effect.

6.4 System 4: OEM's SC strategy management

System 4 is strongly future focused and more involved in strategic management. Here the service portfolio must be elaborated and this should be associated with strategic resources and information, e.g. the warehouse network to commit the service, the repair vendor network, budget, human resources and organization definition, market research, strategic planning, IT, etc. System 4 translates System 5 Board of Directors instructions and, in the other way, translates System 3 information.

Another important role of System 4 is to be in contact with the environment. Then, System 4 is the point where internal and external information can be brought together. System 4 needs to determine where on the efficient frontier to locate (see fig. 3). In order to analyze either external as well as internal data, System 4 uses different DSS or data mining tools to determine the trade-off into the efficient frontier curve for long-range plans.

6.5 System 5: OEM's SC board (policy purpose)

System 5 supplies a logical closure of the system as a whole and defines the identity and ethos of the organization. The main roles of Policy are to provide clarity about the overall direction, values and purpose of the organizational unit; and to design, at the highest level, the conditions for organizational effectiveness. One of the key conditions for organizational effectiveness relates to how the Strategy and Management functions are organized and

interconnected. According with Bar-Yam (2004) “the rule of thumb is that the complexity of the organization has to match the complexity of the environment at all scales in order to increase the likelihood of survival”¹⁰.

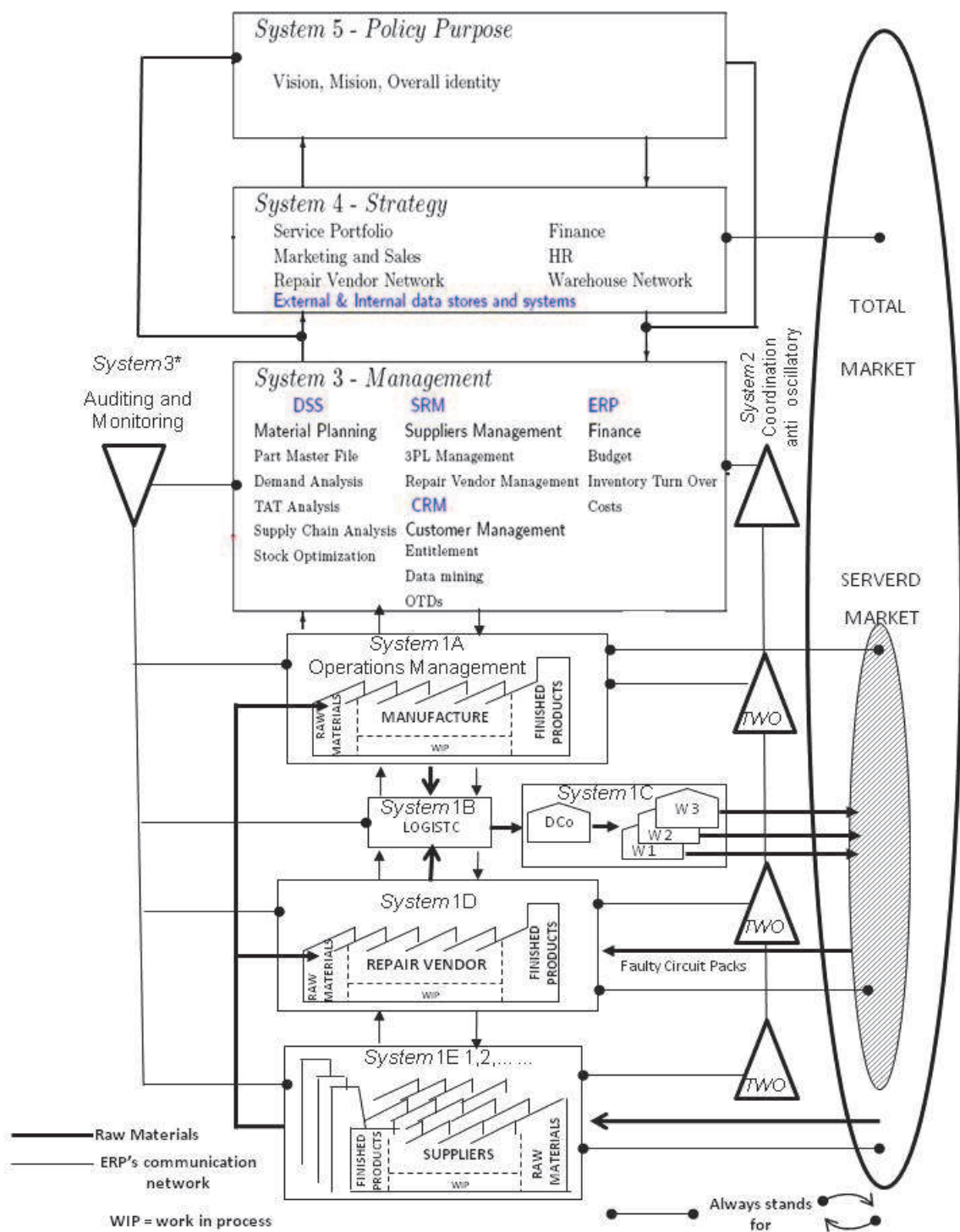


Fig. 4. The OEM’s SC after-sales spare parts services according to VSM and ERP.

¹⁰ Although System 5 organizational effectiveness concern is Strategy and Management, this rule should be apply and permeate through all the organization.

7. Bullwhip effect in after - sales spare parts supply chain, case: Telecomm firms

7.1 General description

The “bullwhip effect” refers to the phenomenon that experienced supply chains when replenishment orders generated by a stage exhibit more variability than the demand the stage faces. For instance, by examining the demand of Pampers disposal diapers, management people in Procter & Gamble realized that retail sales were fairly uniform, however the distributors’ orders issued to the factory fluctuated much more than retail sales (Lee, 1997a). Because all variability must be buffered, the bullwhip effect has important consequences for the systemwide efficiency of the supply chain. Hence, it is necessary to understand what cause this phenomenon. Lee, Padmanabhan and Whang (1998b), identified four factors that lead to the bullwhip effect: batching, forecasting, pricing and gaming behavior, which suggested some options for mitigate it. Bullwhip effect has been analyzed in academic for some time. This phenomenon suggests that demand variability increases as one move upstream in a supply chain. Forrester (1961) observed that factory production rate often fluctuates more widely than does the actual consumer purchase rate and stated that this was consequence of industrial dynamics. Sterman (1989) reported an experiment of a simulated inventory distribution system played by four people who make independent inventory decision without consultation with other chain members, just relying on orders from the other players instead. This experiment was call “Beer Distribution Game” and shows that the variance of orders amplify as one moves up in the supply chain i.e. bullwhip effect. Sterman attributes this phenomenon as misperceptions of feedback of the players.

Lee *et al.*, (1997b) analyzed the demand information flow in a supply chain and identified four causes of the bullwhip effect: demand signal processing, rationing game, order batching and price variations. By identifying these causes, the authors concluded that the “combination of sell through data, exchange of inventory status information, order coordination and simplified pricing schemes can help mitigate the bullwhip effect”. Chen *et al.* (2000) quantified the bullwhip effect in a simple supply chain of two stages. The model includes the demand forecasting and order lead time, which are commonly factors that cause the phenomenon. The work is extended to multiple stage centralized and decentralized supply chains. The study demonstrates that the bullwhip effect can be mitigate but not eliminated. Daganzo (2003, 2004) has been studied the bullwhip effect in the frequency domain. He argued that the bullwhip effect is trigger with all operational inventory control policies, independent of demand process but showed that advance demand information in future order commitments can eliminate the bullwhip effect without giving up efficiency under a family of order up-to policies. Dejonckheere *et al.*, (2003) used control theory to analyze and illustrate the bullwhip effect for a generalized family of order-up-to policies.

The study of supply chain from the point of view of complex dynamical systems theory has started only recently (Helbing, 2008). Concepts from statistical physics and nonlinear dynamics have recently been used for the investigation of supply networks (Radons and Neugebauer (ed.), (2004)). Helbing (2003) generalized concepts from traffic flow to describe instabilities of supply chains. This work remark how small changes in the supply network topology can have enormous impact on the dynamics and stability of supply chains. In order to stabilize the supply chain, some strategies are mention on Radons and Neugebauer (ed.) (2004).

By simulation a supply chain model, Larsen *et al.* (1999) showed a wide range of nonlinear dynamic phenomena that produce an exceedingly complex behavior in the production distribution chain model. Hwarng and Xie (2008) used chaos theory through the Lyapunov exponent across all levels of a specific supply chain. They showed that chaotic behaviors in supply chain systems can be generated by deterministic exogenous and endogenous factors. They also discovered the phenomenon “chaos amplification”, i.e. the inventory becomes more chaotic at the upper levels of the supply chain.

After-sales spare parts supply chains in telecom firms are use to support basically two services: Advance & Exchange (AE) of spare parts and Repair for Services (RfS). This section studies only the dynamics of the AE service in one particular firm¹¹. The AE service is trigger when a critical network element of the carrier¹² fail, then the Telecom Equipment Manufacturer (TEM)¹³ must send to the carrier a good circuit pack from their

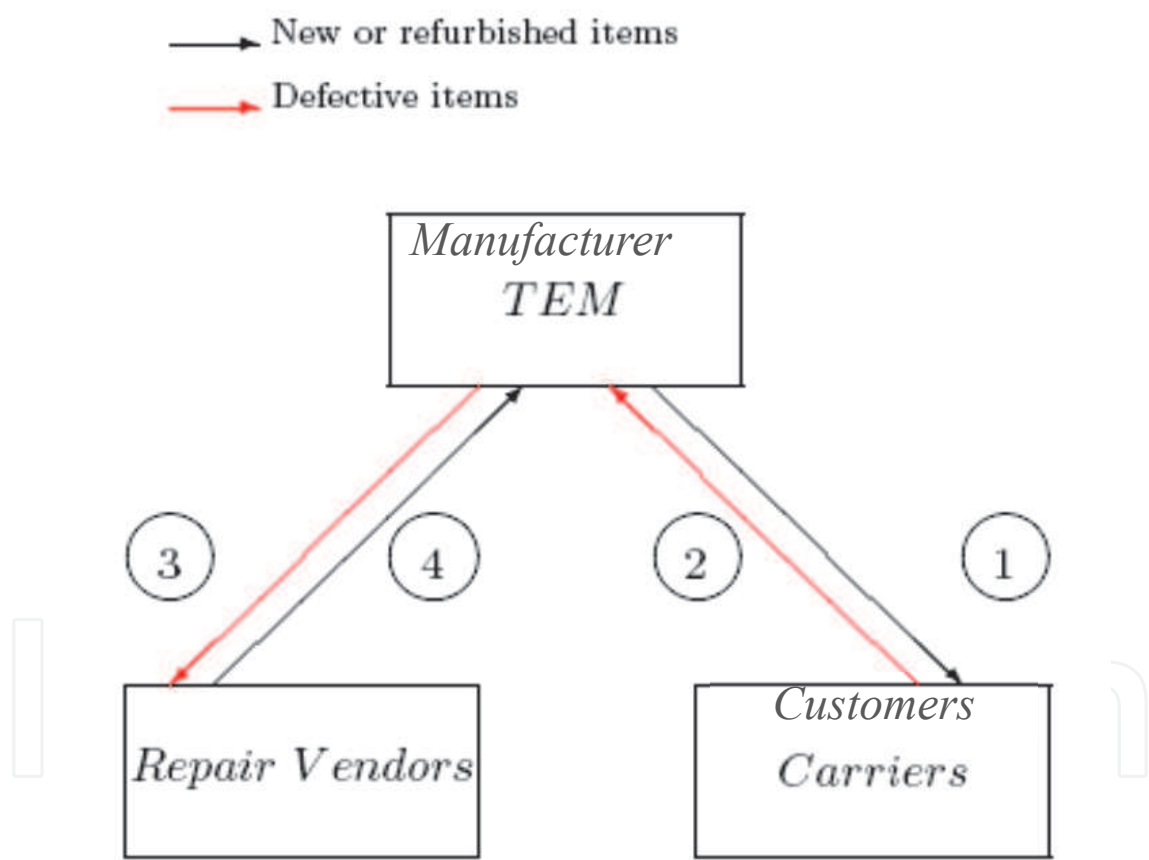


Fig. 5. Closed loop supply chain of repairable items.

¹¹ Because of confidentiality the name of the company and the customer is not shown in this paper.
¹² In the Telecom industry the carrier refers to the customer.
¹³ In the Telecom industry the Telecom Equipment Manufacturer refers to the provider.

stock under a determined Service Level Agreement (SLA), once received, the carrier must return the faulty unit back to TEM's warehouse, so this one can be repair and return back to the pool of good stock (see fig. 5).

The activities that feed and consume the spare parts into the pipeline compose an enormously complex system. The study of complex systems in a unified framework has become recognized in recent years as a new scientific discipline. This approach studies how relationships between parts give rise to the collective behaviors of a system and how the system interacts and form relationships with its environment (Bar-Yam, 1997, 2004). The study of complex systems in a unified fractal framework has become recognized in recent years as a new scientific discipline. The fractal behavior study of complex systems consists in general, in three major approaches: theoretical, experimental and computational. The goal is to have the most parsimonious description of the phenomena under study and the most faithful representation of the observed characteristics (Morales *et al.*, 2010).

The after-sales spare part system to support AE services will be characterized applying fractal theory on the time series of each process described in fig. 5 of the supply chain.

7.2 Fractal analysis

Taking into account the different schools of complex systems, this paper will be focus only on fractals analysis, which is a branch of complexity theory. A fractal can be seen as an object or phenomenon under an invariant structure in different scales. There is no universally agreed definition of exactly what we should mean by a fractal but tow points are central: it should be an object with some type of non-integer dimension, such as Hausdorff dimension¹⁴ (H) and it should be approximately (or statistically) self-affine (Mumford *et al.*, 2002).

The standard definition of self-affine said that a process of continuous time $Y=\{Y(t), t>0\}$ is self-affine if the distribution probability of $\{Y(t)\}$ has the same distribution probability of $\{a^H Y(at)\}$ for $a>0$ (Gao *et al.*, 2007).

The parameter H takes values between 0 and 1 and it is known as the Hurst exponent. This parameter measures the correlation persistence of data of the process a long time.

- For $0<H<0.5$, the process is said to have antipersistent correlation.
- For $0.5<H<1$, the process has persistence correlation and infinite variance.
- For $H=0.5$, the time series is said to be memoryless or short-range dependence.

To estimate H we use the method rescale range (R/S) analysis. This method allows the calculation of the self-similarity parameter H , which measures the intensity of long-range dependence in a time series (Mandelbrot, 1982). Mathematical calculation details are shown on Annex 1.

The time series are plotted using cumulative data of each echelon of the process of the supply chain (Daganzo, 2003) (see fig. 6). The vertical difference between two curves represents the queue of material which exists in the process and the horizontal difference means the elapse time one unit use to go from one echelon to the next one.

In order to avoid the bullwhip effect the value of H might be almost statistically the same in each echelon into the supply chain, i.e. that each curve in graph shown below might be statistically symmetric.

¹⁴ See the definition of Hausdorff dimensión in Barnsley (1988)

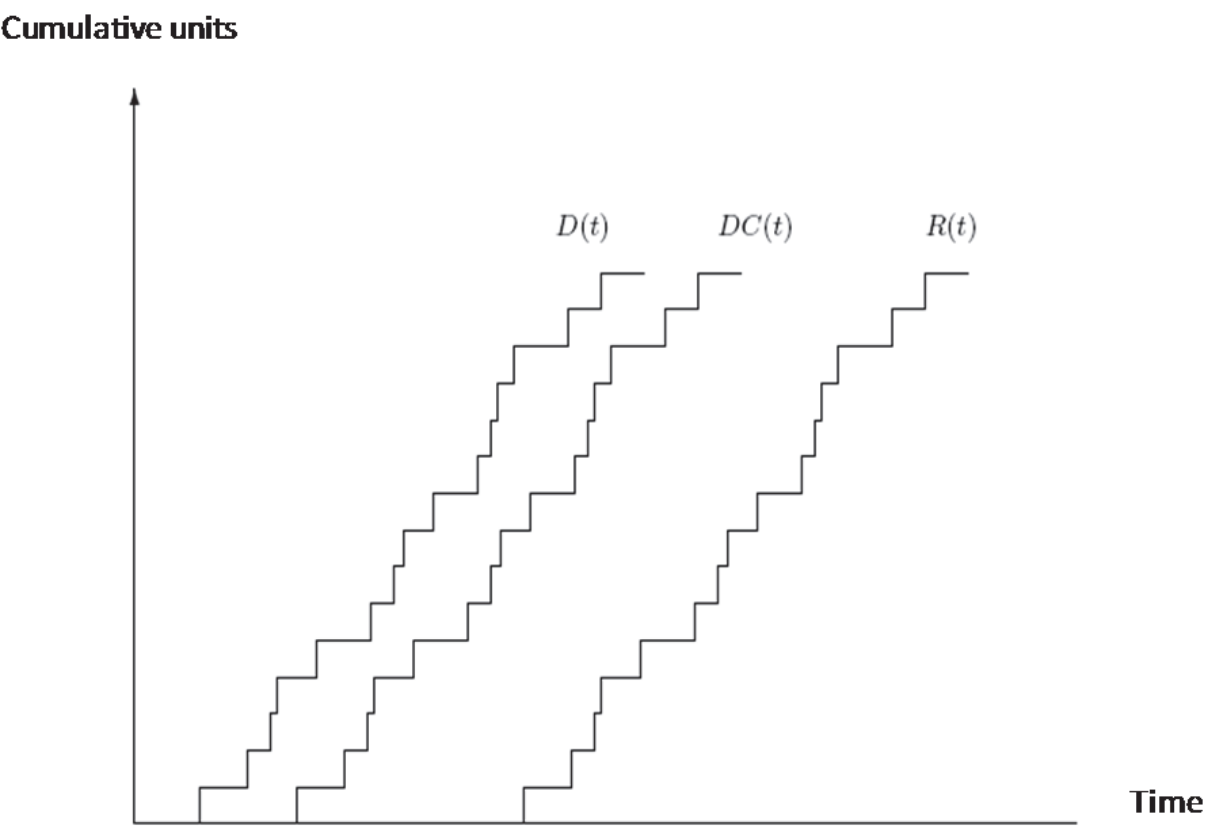


Fig. 6. Supply chain cumulative data of demand, collect and repair process.

7.3 Results

The time series encompassed one year of failures (demand of spare parts) of 4217 units. Unfortunately not all defective units were collected and/or repaired. Then, only 3617 units completed the entire process, i.e. since they were demanded until repaired. Fig.7 shows the cumulative data of the real time series of each process of the supply chain. We can observe on this graph that there is some symmetry between each process. However, some simple statistics of these time series (see table 5) show an increased in the variance between the demand and the other processes. This suggests the presence of the bullwhip effect in the supply chain¹⁵.

	Demand	Defective Collect	Inbound Repair	Outbound Repair
Media	9.909589041	8.334101382	8.334101382	7.795258621
Standard Deviation	7.087757678	8.592998291	11.46805537	9.128734872

Table 5. Simple statistics of the time series of the supply chain

¹⁵ This analysis considers a different perspective of traditional definition, where the creation of the orders is considered in the analysis and in this paper is the completion of them.

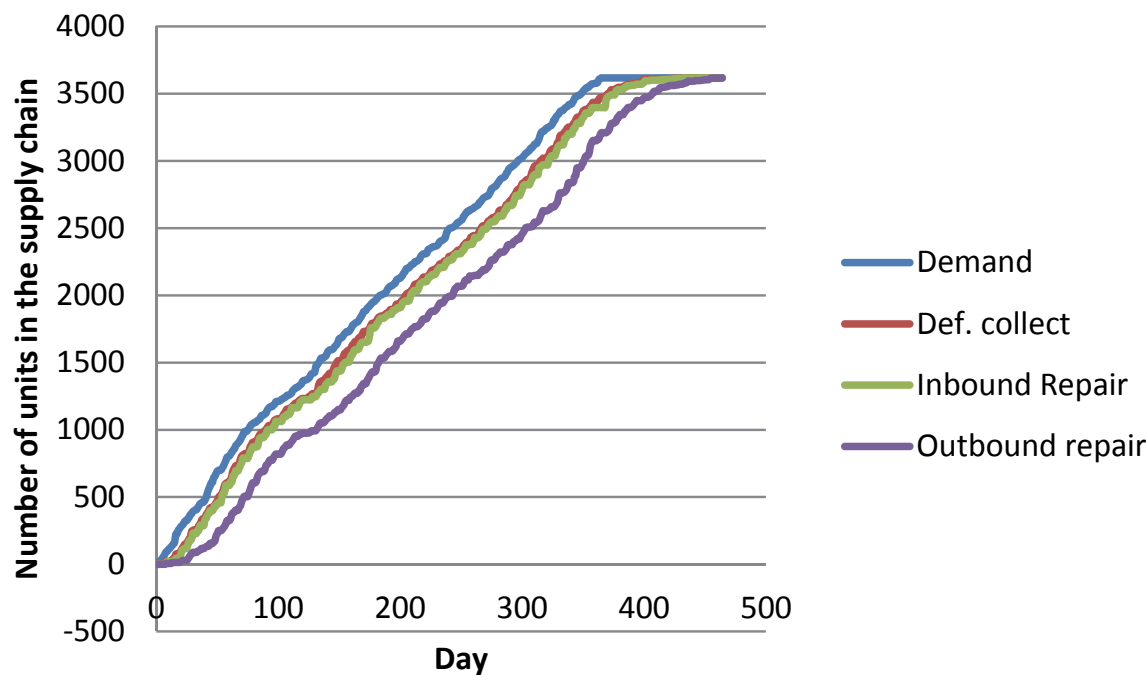


Fig. 7. Cumulative real data of the supply chain of spare parts.

Another way to look at the data is by calculating the difference among two cumulative curves of the process, i.e. the queue of material pending to be process by the following steps of the supply chain.

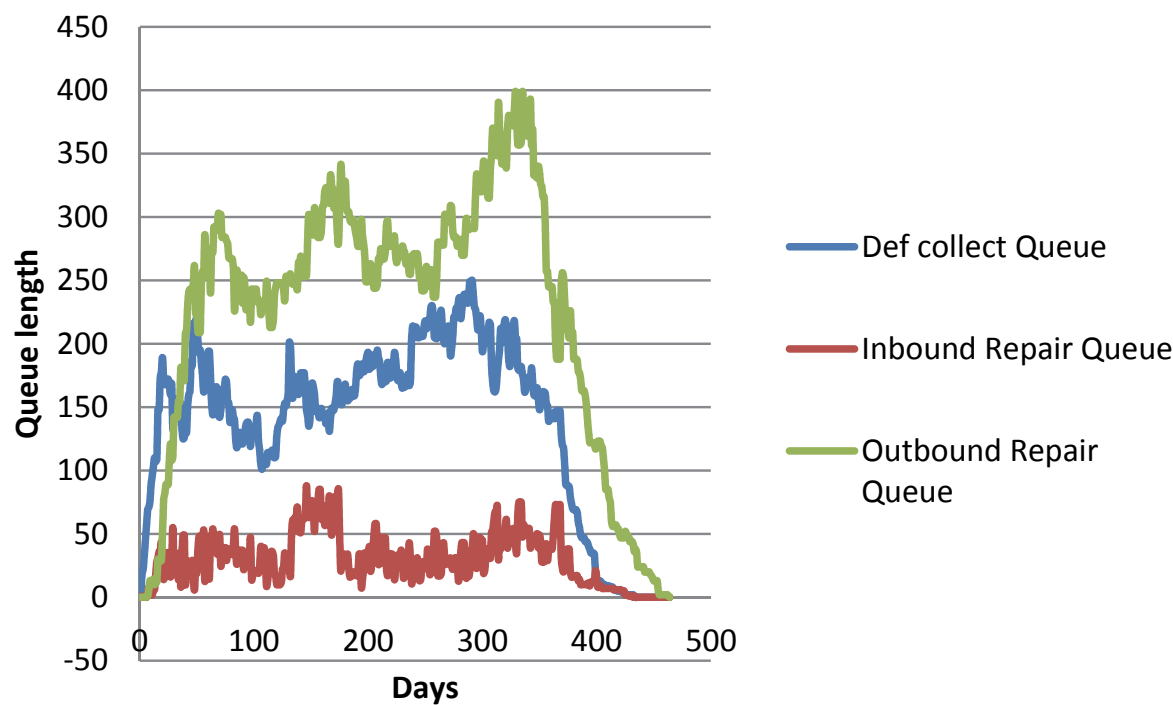


Fig. 8. Queue of parts pending to process in each echelon.

Fig. 8 illustrates the difference among each queue length. The repair queue has an average of 223.42 units and standard deviation of 105.03 units, which is the largest queue. The defective collect queue has an average of 147.70 units and a standard deviation of 60.91 units, which is the second largest queue. The smallest one, is the queue related with the units pending to be inbound in the repair process with an average of 32.40 units and a standard deviation of 19.49 units. The formation of these queues are closely linked to the time and uncertainty of each process.

To conclude this analysis, the Hurst exponent estimated through the R/S method, suggests that the demand process in the AE service shows persistence with a Hurst exponent value of 0.8449, and the defective collect process indicates still the presence of persistence with a Hurst exponent value of 0.6481. However in the following steps of the processes, the value of the Hurst exponent decreased with a value close to 0.5, which suggests that they follow a Brownian Motion process (see Annex 2). In other words, it is notorious in this analysis that the system started to have strong long-range dependence but at the end it became almost memoryless.

Summary	H
Demand	0.8449
Defective collect	0.6481
Inbound repair	0.5164
Outbound repair	0.5649

Table 6. Hurst exponent value of each process of the supply chain.

In Annex 2 there are four figures that refer to the log-log graphs of the Hurst exponents analysis, computed with the Benoit 1.3 software, for Demand, Defective collective process, Inbound to repair process, and Outbound process.

These results come up with a different way of detecting the bullwhip effect. By intuition, the bullwhip effect would not occur if a statistical symmetry between each time series of each process in the supply chain is not broken, but unfortunately in this case, current models in the literature have this assumption (Sherbrook, 2004; Muckstadt, 2005).

8. Conclusions and recommendations

The Systems Science perspective provides a framework to better comprehend the Supply Chain Management System. This approach described how to adapt the VSM and ERP to the case of OEM's SC of a Telecom Firms. Each subsystem of the VSM represents several functions from the operations to Board of Directors. The idea of this work is to provide also the ability to balance both internally and externally factors, making the SCM adaptable to changes.

Bullwhip effect is a phenomenon experienced by supply chains when demand at the top tends to exhibit more variability than demand at the bottom. This work provides new insights to develop a new model of the spare part management which captures the characterization of the supply chain.

Some recommendations follow:

1. Avoid barriers due to lack of trust between suppliers and manufacturers

- 2. Collaborate with suppliers to interface the ERP modules to their production systems
- 3. Integrate ERP with all Tiers of critical Suppliers
- 4. Educate an train suppliers in operation of specifics ERP modules such as: MPS, MRP, BOM, IM,CRP, DRP and S&OP
- 5. Other concepts from systems theory, systems dynamics, knowledge management, complex systems, etc. can also be analyzed in a future research to incorporate methodologies or concepts that help better understand the dynamics of the supply chain service part system; however, this initial proposal can be use as a guide for diagnosing.

Annex 1

The fractal analysis begins with dividing a time series of length L into d subseries of length n . Next for each subseries $m = 1, \dots, d$: 1° find the mean (E_m) and standard deviation (S_m); 2° normalize the data ($Z_{i,m}$) by subtracting the sample mean $X_{i,m} = Z_{i,m} - E_m$ for $i = 1, \dots, n$; 3° create a cumulative time series $Y_{i,m} = \sum_{j=1}^i X_{j,m}$ for $i = 1, \dots, n$; 4° find the range $R_m = \max\{Y_{1,m}, \dots, Y_{n,m}\} - \min\{Y_{1,m}, \dots, Y_{n,m}\}$; and 5° rescale the range R_m/S_m . Finally, calculate the mean value $(R/S)_n$ of the rescaled range for all subseries of length n . It can be shown that the R/S statistics asymptotically follows the relation $(R/S)_n \sim cn^H$. Thus the value of H can be obtained by running a simple linear regression over a sample of increasing time horizons (Weron, 2001).

$$\log(R/S)_n = \log c + H \log n.$$

Annex 2

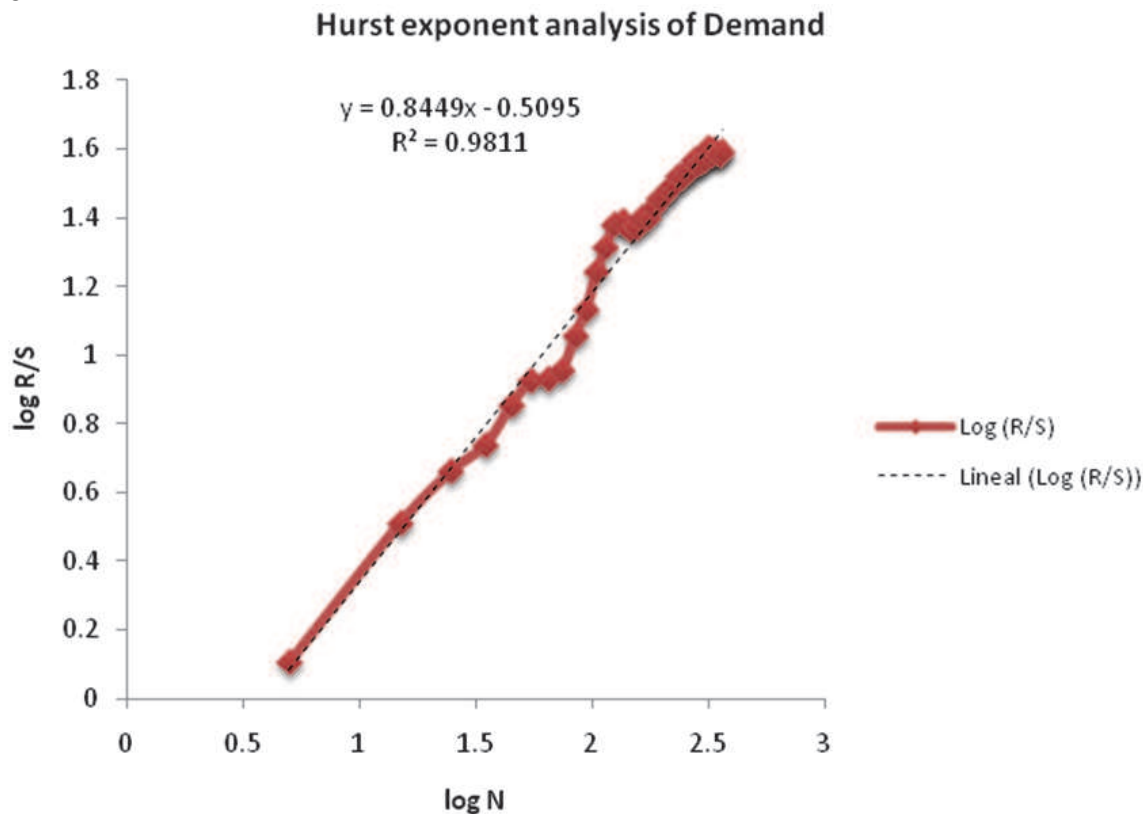


Fig. 9. R/S analysis of demand data ($H=0.8449$).

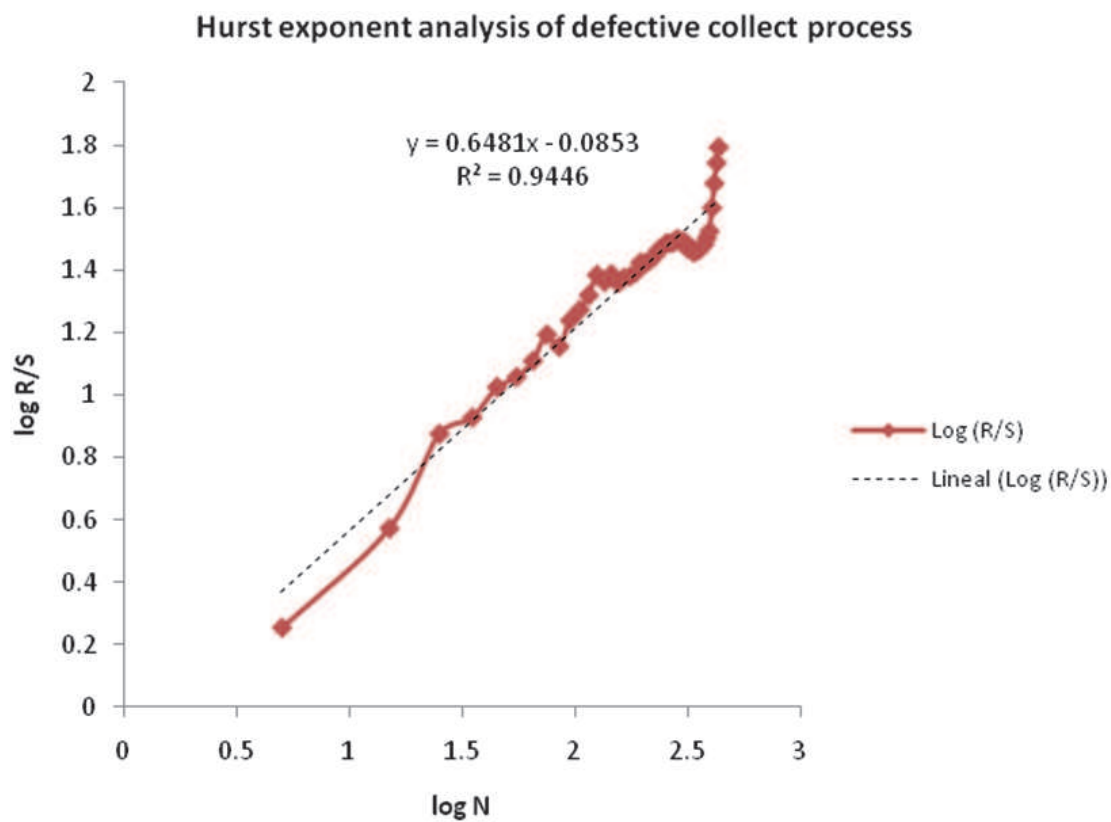


Fig. 10. R/S analysis of defective collect process data ($H=0.6481$).

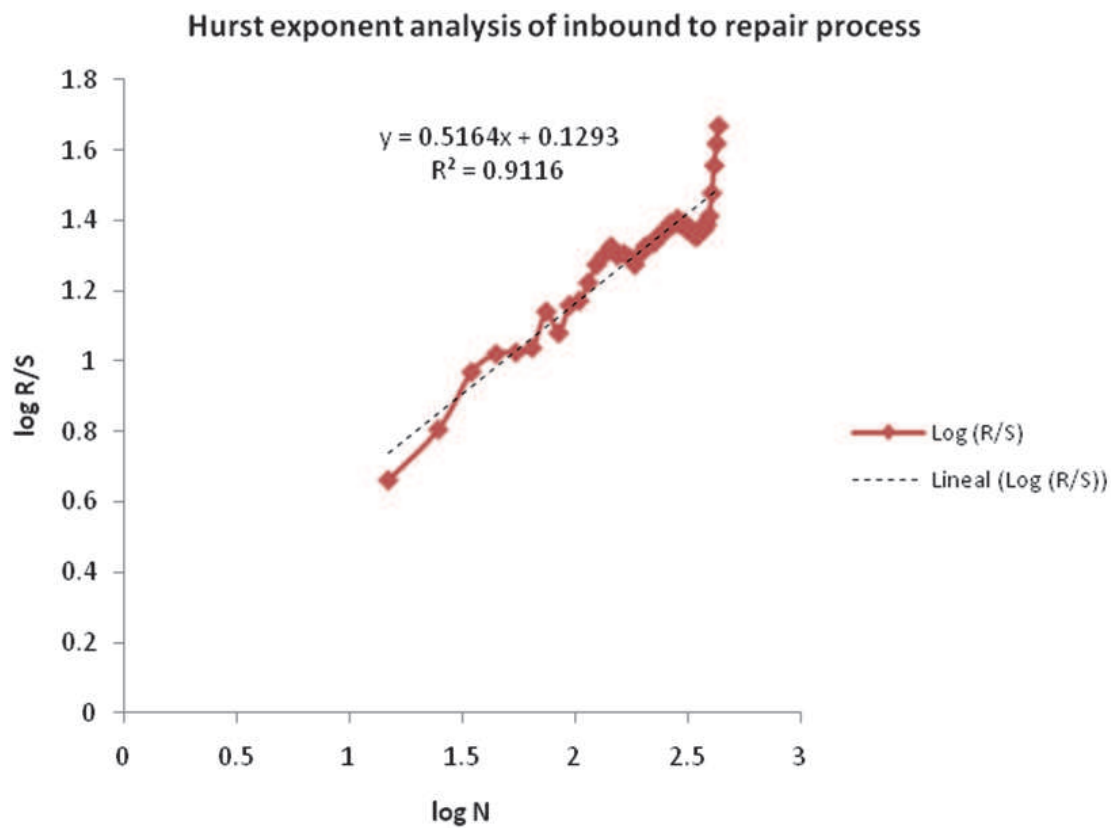


Fig. 11. R/S analysis of inbound to repair process data ($H=0.5164$).

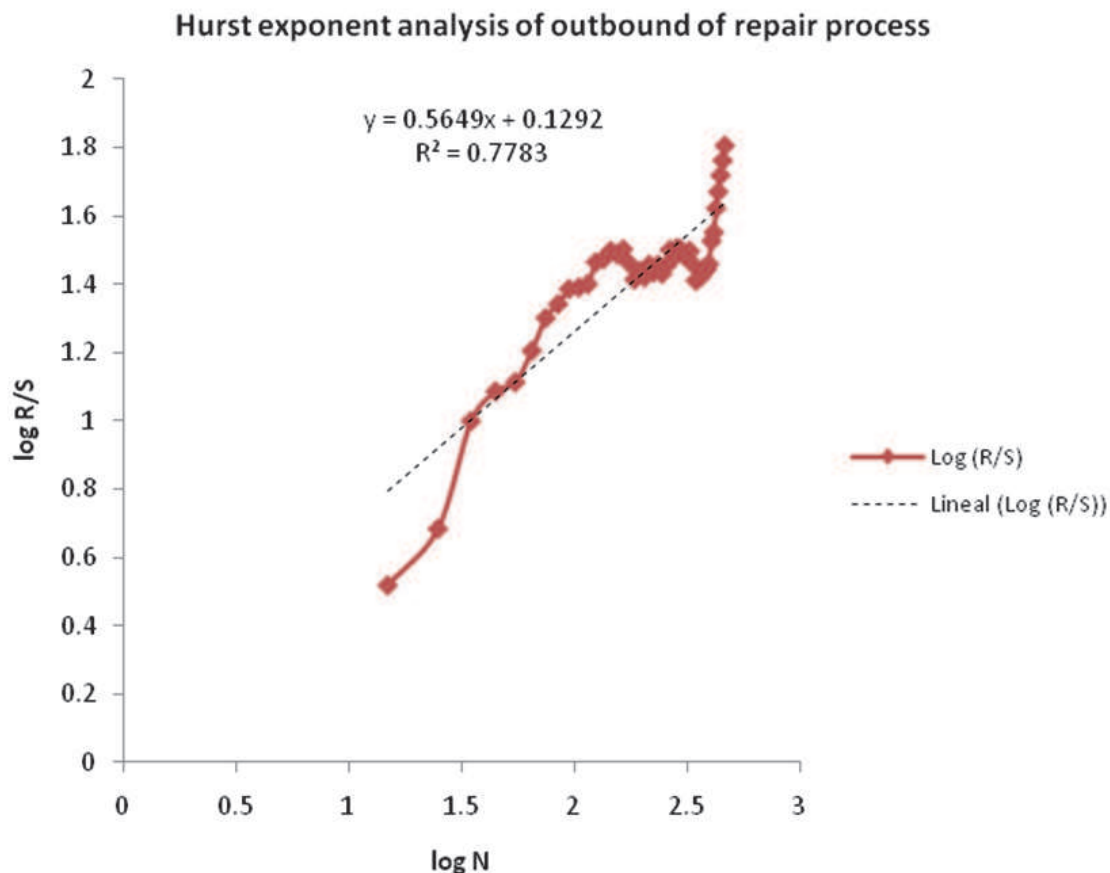


Fig. 12. R/S analysis of outbound of repair process data ($H=0.5649$).

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Over the past few decades the rapid spread of information and knowledge, the increasing expectations of customers and stakeholders, intensified competition, and searching for superior performance and low costs at the same time have made supply chain a critical management area. Since supply chain is the network of organizations that are involved in moving materials, documents and information through on their journey from initial suppliers to final customers, it encompasses a number of key flows: physical flow of materials, flows of information, and tangible and intangible resources which enable supply chain members to operate effectively. This book gives an up-to-date view of supply chain, emphasizing current trends and developments in the area of supply chain management.

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