Chapter 7

A Systems Science/Cybernetics Perspective on Contemporary Management in Supply Chains

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Additional information is available at the end of the chapter

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1. Introduction

The management of supply chain is a special field of the general management for production and services systems. This special kind of management is required to be adaptive to the nature of the industry evolution. The current industry is distributed around geographic places different for the main production plan.

In this chapter it is going to be described, from a systems science perspective, how will the new nature of the industrial processes be managed. In systems sciences, there is one management principle - to know the Ashby's law: "the variety of ability to response to the industrial processes and the environment change should be greater than the variability on industrial processes and of the environment

To describe accurately Supply Change Management (SCM), we are going to use the official concepts of the American Production and Inventory Control Society (APICS) Dictionary "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 measuring performance globally" [1]. There are several functions included in the definition of SCM which are represented in Systems Science with a Mode called Viable System Model (VSM) [2]. For example, the **scheduling** and **execution** is the main function of component number 1 of the VSM. The **control** is the task of component number 2 of VSM. The **monitoring** and **auditing** is the task of component number 3 and 3*of VSM. The **planning** is the function of a component number 4 of VSM. The creation of **net value** is the main task of component number 5 of VSM.

The **design and diagnosis** of the full SCM system is the main function in VSM. All the five components of VSM interact inside by information systems called Enterprise Resources Planning System (ERP).

In this chapter we are going to make a brief description of SCM and VSM. At the end of the chapter an application emphasizing the bullwhip effect is presented.

In [3] it is reported an industrial case of DuPont"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".DuPont management started its SCM with ERP implementing several modules like Material Requirement Planning (MRP), Customer relationship management (CRM), etc.

2. Systems/cybernetics sciences

In accordance with the title of this chapter, it is convenient to define some systems concepts.

Cybernetics. Studies the flow of information around a system, and the way in which this information is used by the system as a means of controlling itself: it does this for animate and inanimate systems indifferently [4].

Environment. The set of systems in which is immersed the system in focus.

Function. The main activities performed by the system to reach the purpose.

Human activity system. A special system composed mainly for functions performed by human beings.

Model building. To abstract the main attributes from a portion reality interest, in order to obtain a conceptual representation.

Recursion (a level of). A level at which a viable system is in operation as an autonomous part of a higher-level viable system, and contains within itself parts which are themselves autonomous viable systems [5].

Subsystem. Is a component which is embedded in a superior system.

System. A set of interrelated components with a purpose whose boundary are defined by the observer

Systems science. A scientific field to research taxonomies, concepts, theories, and methodologies. According to [6] the field of scientific inquiry whose objects of study are systems.

Variety. Number of possible states that a system is capable of exhibiting [7].

Viability. The ability of a system to maintain a separate existence [7].

Viable system model (VSM). According to [2], is a system able to maintain a separate existence, capable of maintaining its identity and transcend independently.

Systems science uses the construction of models to represent real systems; for example, the viable system model (VSM) was elaborated by Beer [7] to represent human activity systems like as SCM.

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The VSM is a recursive model that represents viable organizations, the viability are based on five functions or subsystems. A viable organization is integrating by viable sub-organisations and at the same time the organization is embedded. In the VSM there are five interactive systems [8]. In order for an organizations to survive changes on the environment it is necessary to have the five subsystems of VSM. Change in the environment could include socio-political new laws, change in the global economy, etc. The five subsystems are designated in this chapter as follows: operations 1, coordination 2, and plant management 3 which includes auditing/ monitoring 3*, strategic management 4, and board of directors 5.

All the five subsystems should be interconnected by a management information systems like as ERP. There are several information systems in the market, the selection of any one depends on the characterization of each SCM.

3. The VSM: Brief narrative

In figure 1 it is shown the three basic components: environment system, operating system and management. The three basic components are interrelated by information channels, subject to the Ashby's law. The Ashby's law established that the variety of the management system should be grater or equal to the variety of the operating system. The variety of operating system should be larger or equal to the variety of the environment system [9].

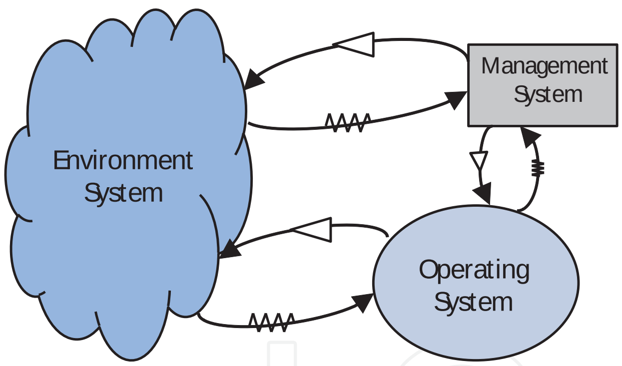

Figure 1. A simplified model of a production system

Human organizations are much more complex than we are usually prepared to admit. Organizational charts do not show how the organization really works, and in fact, real-world systems have variety which is effectively almost infinite. Consider Fig. 2 as a model of a simplified production system.

The VSM has the ability to maintain its identity according to the general purpose on the organization. The VSM model could be used to design new organization or diagnosing current organizations [10]. 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 [11], but also in financial management and in the service industry.

For further details of the five subsystems components and its interrelations see [7] and [8].

3.1. Modelling a general SCM with VSM and ERP

In Fig. 2 we present an SCM according to the VSM interconnected with ERP.

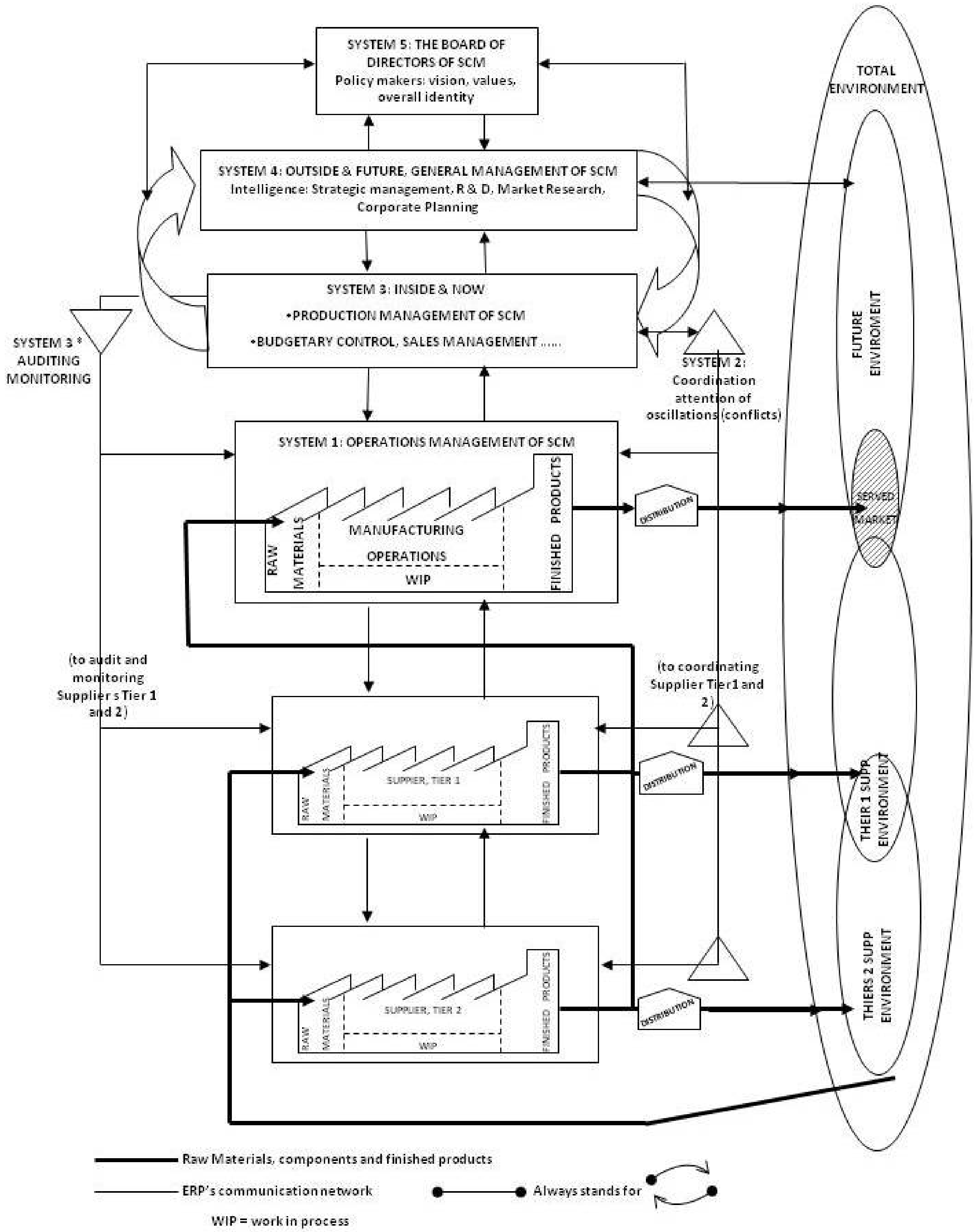

Figure 2. A general supply chain management model based on VSM.

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System 1: It is the component of a production system that perform tasks which produce what the systems is supposed to do. Some of the task performer by system one are facilitated by ERP modules like those shown in table 1.

1. Sales and operation management (SOP) to develop tactical and strategic 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 schedule
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 labour and machine resources required to accomplish the MPS
7. Bill of material (BOM), an organization of the product structure	8. Bill of processes (BOP), an organization of the processes of manufacturing
9. Shop floor control (SFC) Control of manufacturing activities	10. Production activity control (PAC), control of manufacturing activities.
11. Supplier relationship management (SRM), relationships with vendors.	12. Total quality management (TQM)
13. Maintenance management (MM), Preferably total quality maintenance.	13 Distribution requirement planning (DRP), to improve logistic of parts and finished products.

Table 1. ERP's modules for system 1 of VSM [11].

All components of the supply chain, are interconnected between them and to a management suprasystem. In order to facilitate management of variety, currently screens to receive instructions and to report performance, are used. The organization viability of the total systems and its components are inherent to the VSM. Which include communications of decisions according to Master Production Schedule. The ERP system reduce the bullwhip effect, with the help of one of the modules of ERP called distribution requirement planning (DRP). The algorithm of this module avoids the quantitative subjective process of planning order receipts (see Fig. 3).

System 2: Is a system that coordinates the activities of various productions departments, in order to avoid conflicts between them when using common resources of services. This coordination activity avoid the problematic situation known in systems dynamic, as "tragedy of the commons". Coordination activities are based on what is best for the whole (see table 2).

Systems 3 and 3*: System 3 activities are the command and control of the operations of system 1, with the help of information from system 2 and the monitoring or auditing information from system 3*.The main activities of system 3 are supported by the modules of ERP shown in table 3.

Warehouse "A"

Lot Size: 150 Lead Time :3 weeks		Week							
		1	2	3	4	5	6	7	8
Forecast		80	70	70	60	50	50	70	60
In Transit									
Projected on Hand	250	190	120	50	140	90	40	120	60
Planed receipt					150			150	
Order release		150			150				

Warehouse "B"

Lot Size: 100 Lead Time :2 weeks	Week							
	1	2	3	4	5	6	7	8
	40	40	30	35	40	35	35	40
		100						
75	35	95	65	30	90	55	20	80
					100			100
				100		100		

Lot Size: 300 Lead Time :3 weeks		Week							
		1	2	3	4	5	6	7	8
Distribution demand		150		100	150		10 0		
Schedule receipt									
Projected on hand	250	100	100	0	150	150	50	50	50
Master Scheduled Receipts					300				
Start master schedule		300							

Source: APICS

Figure 3. Two-tier distribution requirement planning (DRP) example.

- 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 of VSM [11].

The work of the accountants will be facilitated with the online data communications [13], this online data collections is performer with one module of ERP [14]. The free time of the accountants now will be dedicated to assist management in the system 3. In addition to the free time of the accountants could be used to improve performance of management (system 3). Real time data will be filtered to adjust variety of system 1.

In others words auditing/monitoring coordinates and control system 1 through some ERP modules, 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); which are standard modules of ERP

System 4: System 4 performs strategic planning and interpretation of polices elaborated by system 5. Some of the tasks of system 4 are supported by modules of ERP shown on table 4. System 4 is the point where internal and external information can be brought together.

Shop floor control (SFC)	Financial business modules such as:
Manufacturing execution system (MES) (to control and monitor plant-floor machines and electromechanical systems)	Activity-based costing (ABC) to obtain 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)
Cost Accounting of BOM's and BOP's (CA)	Financial supply chain management (FSCM)
Manufacturing execution system (MES) (to control and monitor plant-floor machines and electromechanical systems)	Payroll (PR) for salary administration
	Profit and cost centre accounting, etc.

Table 3. ERP's modules for system 3 and system 3* of VSM.

Human resources (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 [11].

According to [11]:"The database of the human resources module (HR) helps to build a portfolio of human resources, by identification of employees. The system 4 use modules of ERP like shown in table 4. This system maintain procedures to forecast future changes of equipment in other resources for example 3 D printers instead of traditional tool-room equipment.

System 5: System 5 keeps enterprise identity and congruency with its environment. This System is integrated by board of directors. One of the main the outputs of the board of directors is to issue general management policies for inside operation system as well as the interrelation with the environment. ERP is lacking appropriated modules for the activities of system 5, this fact is an opportunity to improve ERP [11]. At the present there are not modules of ERP to help activities of system 5. For example, to improve decision taking on consensual agreements, strategies and policies, could be based on methodologies such as Syntegrity [15], Interactive Management [16] or CogniScope [17]. In case of critical situations, the algedonic channels communicate this situations directly to system 5.

4. Case Study: VSM applied in an aftersales spare parts service in telecommunications industry

According to [18] "all economic activities whose output is not a physical product or construction, is generally consumed at the time it is produced, and provides added value in forms (such as convenience, amusement, timeliness, comfort or health) that are essentially intangible concerns of its first purchaser". Fitzsimmons and Fitzsimmons says the society is changing from a manufacturing-based society to service based society [19]. Modern telecommunications are like a catalyst of states' sustainable development: these represent a vital element in the proper functioning of enterprises, and are part of the quotidian life of almost every individual on this planet [20]. The telecommunications industry requires main preventive and corrective maintenance of high service level which includes, spare parts, technical support and training. This kind of maintenance offered by original equipment manufacturer (OEM). The corrective maintenance is offered after sales [21]. This case of study concerns only the level of an OEM dedicated to aftersales spare parts service. Customer operators (CO) try to reduce capital expenditures and inventory cost, as well as to improve cash flow. In reference [22] it is say, that 47 % of mobile CO outsource spare parts activities.

In the area of service parts, the relationships between OEMs and COs are often established through detailed service contracts. In this contracts are specified the delivery time, prices, etc.

The purpose in this section is the VSM application in an aftersales spare parts service in telecommunications industry. If the organization adopt the VSM it will improve the total performance. For example reduces inventory, reduces delivery time, better relationships with suppliers and customers, etc.

5. Service of spare parts to an original equipment manufacturing telecommunications industry

There are different aftersales services that OEMs provide to their customers, for example return for repair (RfR), advance and exchange (AE), spare parts, field corrective maintenance, etc. As stated before, OEMs and COs establish the service scope through an agreement. In this agreement it is specify several aspects of service delivery, for example the metrics to measure the effectiveness of the service [23]. According to [24] the service level agreement (SLA) should be identify include the geographic region.

In this particular industry the two kind of repair services are AE and RfR (see Fig. 4). Some details of the process are as follows: issue of a requisition of spare parts which should be delivery in two, four or twenty four hours in according to SLA document. The delivery is done from the near warehouse ($W_{1\text{-}n}$). At the same time, the main warehouse centre (DC), delivers the parts to the local warehouse in order to maintain inventory level. As soon the goods parts are on hand at the OEM, it returns the failed part, afterward the defective part is delivery to the repair centre; when repaired part it is delivered to the distribution centre (DC). The total time elapsed since the requirement order to the delivery of the repaired part, is called the turnaround time (TAT). In case of urgent repair service the best alternative is the AE.

There are two types of variability in the AE services: 1) the variety of the demand/failure of parts process; 2) the variety in defective collection process. In order to tackle the first variability. To cope the variety 1), the OEM uses a database and part failure rate [25] to forecast requirements (demand). The other source of variability is located inside the OEM operator and depends on the speed on return of failed spare parts [26].

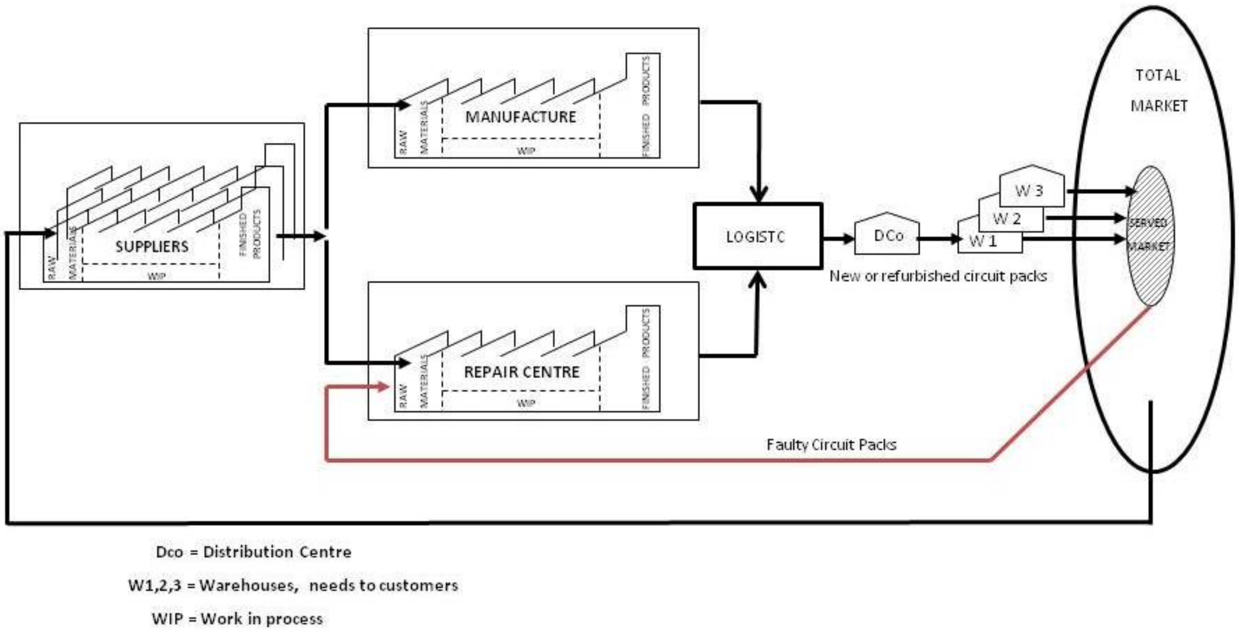

Figure 4. Schematic of materials flow in an aftersales AE spare parts service SC.

6. Modelling an 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 and the costs.

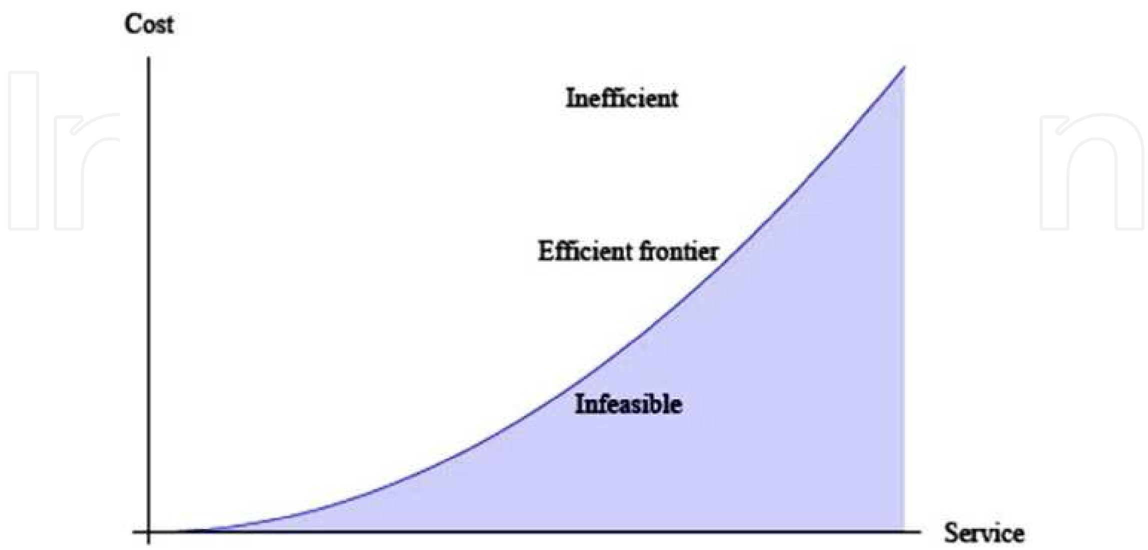

Figure 5. Service cost trade-off and the efficient frontier.

6.1. System 1: Operations of SC of OEM

This system develop the physical operations required to give AE and RfR services. The main operations performed in System 1 are: replenishment, rebalances, redeployment, new purchase and disposal of scrap inventory. In order to reduce inventory cost and service failure risk, it is recommended RfR services (see Fig. 5). The ERP system consider all the above transactions.

6.2. System 2: Coordination and anti-oscillatory actions

In Fig. 6 the supply chain shown several organizations levels. According to [27], it is necessary to coordinate: (i) bottlenecks, (ii) variability; (iii) conflicts on of resource utilization, (iv) lot size. The increase variability is referred to as the inefficient bullwhip effect [28]. To reduce the bullwhip effect it is required a good coordination between supply and demand. There is another needed coordination between the information flow and the spare parts flow; the last taking in consideration that the repair centres are located in several countriesThe lack of coordination between the flows of information and spare part, are very expensive in money and [29]. According to Bar-Yam [30], the structure of the hierarchical organization also coordinates the tasks of different individuals in the supply chain. All flows: material, data and money are properly registered by the ERP system.

6.3. System 3 and 3*: General management and auditing/monitoring activities

System 3 attended the now and here activities of the aftersales spare part service. For example: quality and punctuality of delivery are KPI's. The customer relationship management (CRM) module of ERP helps to perform this activities. MRP helps to perform the material planning activities for example: identification of failed and missing parts.

At the same time, system 3 perform the activities related to the supplier relationship management (SRM) and purchasing activities.

System 3* the surveillance and audit of system 3, control the quality of the service operations management. The control information is used to improve the output of System 1. The auditing information of system 3 together with the strategic management information of system 4 is used to establish the master operation plan.

System 3 knows that sales forecast and other variables are always wrong. Following [31], employees working in systems 1, 2 and 3 interpret strategies of system 4, corporate policies and business plan of system 5 with the help of ERP identified lead times, capacities, level of quality service and production schedules.

To improve the inventory management of spare parts, considering the bullwhip effect, in section 7 it is applied the fractal theory to characterize the number of failures in spare parts.

6.4. System 4: Strategy management of SC of OEM

System 4 see the future in the outside of services enterprise, for example budget, human capital in future organization change; market research and research and development of future kind

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of services. Briefly system 4 use internal and external information to position the services enterprise and suggest future orientation, according to the growth market.

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

System 5 The mains roles of this system is to establishing cultural and social identity, for example to establish values and purposes, social benefits and others internal policies. In reference to [30], "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", which is an extension of the Ashby law of requisite variety; "only variety can absorb variety" [2].

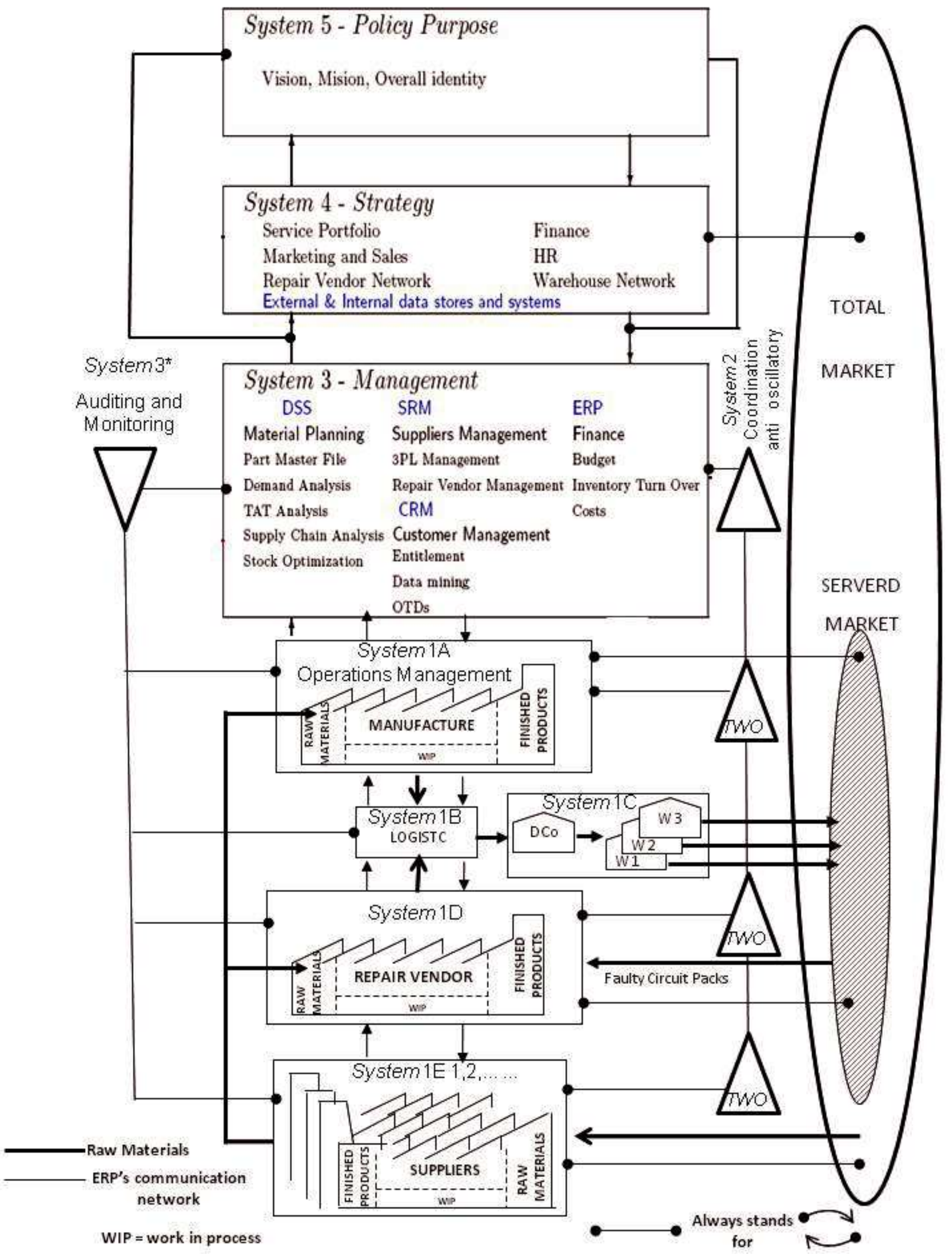

Figure 6. The OEM's SC aftersales spare parts services according to VSM and ERP.

7. Bullwhip effect in aftersales spare parts supply chain, Case: telecommunications industry

7.1. General description

The "bullwhip effect" is defined in [1] as "an extreme change in the supply position upstream in a supply chain generated by a small change in demand downstream in the supply chain. Inventory can quickly move from being backordered to being excesses". An example of this effect was reported by [28] in Procter & Gamble where variability of supply order to replenish the upstream distribution inventory was larger than the variability of downstream retail inventories. To cope with unexpected variability it is necessary to increase the safety buffer levels upstream, causing cost inefficiency to the total system of SC.

Of course the bullwhip effect is not new since the foundation of industrial dynamic in 1958 by Forrester [32] up to S Lee, Padmanabhan and Whang [33], and Sterman [34] have published about this effect. Some authors have identified several causes of the bullwhip effect, for example [1] attributed the effect to "the serial nature of communicating orders up the chain with the inherent transportation delays of moving product down the chain. [33] Identified four factors: batching, forecasting, pricing and gaming.

Chen et al. introduced quantitative relations in supply chain [35]. [36, 37 and 38] used control theory to illustrate the bullwhip effect. The study of supply chain from the point of view of complex dynamical systems theory has only recently begun [39]. Concepts from statistical physics and nonlinear dynamics have recently been used for the investigation of supply networks [40]. The authors Helbing [39] and Radons & Neugebauer [40] have researched nonlinear causes of the stability of SC.

By simulation of a supply chain model, Larsen et al. [41] showed a wide range of nonlinear dynamic phenomena that produce an exceedingly complex behaviour in the production distribution chain model. Hwarng and Xie [42] used chaos theory through the Lyapunov exponent.

In figure 7 it is shown the interaction/transportation relationships, under the service level agreement (SLA), between telecommunications equipment manufacturer (TEM), repair vendors (RV) and Carriers (C)

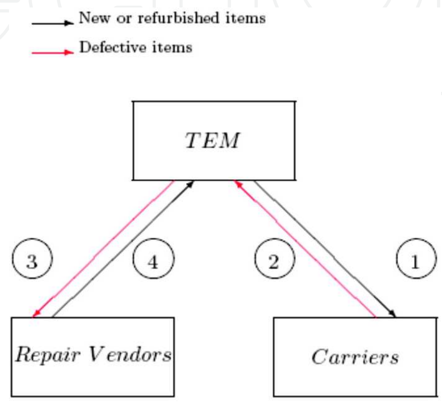

Figure 7. Closed-loop supply chain of repairable items.

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The fractal behavioural study of complex systems consists, in general, of three major approaches: theoretical, experimental and computational. The goal is to create the most parsimonious description of the phenomena under study and the most faithful representation of the observed characteristics [30, 43 and 44].

One of the fractal characterization technics is based in the methods of Scale range (R/S). This is the method that will be explained in nest section.

7.2. Fractal characterization

The fractal characterization applied in this chapter is oriented to the self-affine processes [45].The standard definition of self-affine states 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 {aHY(at)} for a>0 [46].

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 over a long time.

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

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 [47 and 48].

The time series are plotted using cumulative data of each echelon of the process of the supply chain [36, 37]. In Figure 8, the vertical axes show the cumulative units in queue of spare part. In the horizontal axes show the average difference of elapsed time that one spare part need to be transported from one echelon to the next one. The curves should be almost statistically the same in the each echelon and statistically symmetric. The meaning of each curves are: *D(t)*=Demand, *DC(t)*=collect spare parts, *R*(t)=Repair processes.

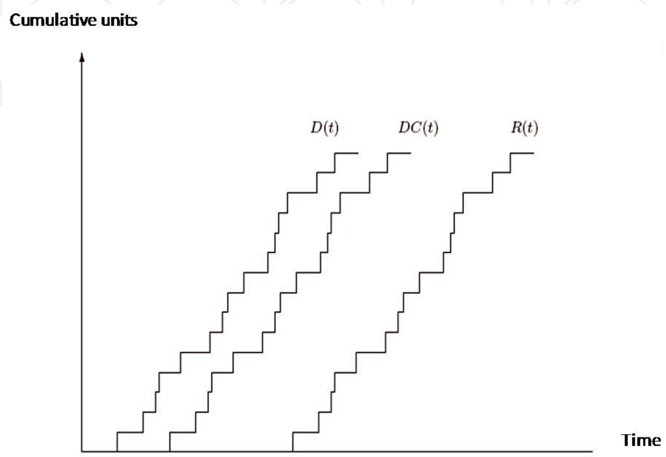

Figure 8. Data of Demand, Collect and Repair

7.3. Results

The actual data for spare parts are 4217, due to some exceptions, the number of spare parts was reduces to 3617. In Figure 8 it is observed some symmetry between the three curves. After some statistics of the time series it is detected a large variance between demand and others processes (see Table 5), which suggest bullwhip effect.

	Demand	Defective Collect	Inbound Repair	Outbound Repair
Median	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

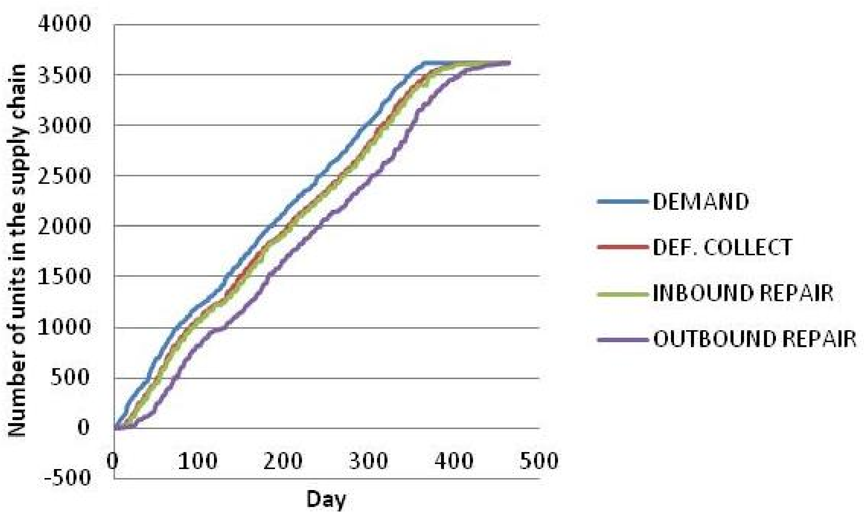

Figure 9. Data of the spare parts in SC.

Another way to look at the data is by calculating the difference between two cumulative curves of the process, i.e., the queue of material waiting to be processed by the following steps of the SC.

In Fig. 10 it is shown statistical characteristics of tree queues: the average of the repair queue (223.42 units), standard deviation (105.03 units). Average of collection queue (147.70 units), standard deviation (60.91 units). Spare parts waiting to the repair process: average (32.40 units), standard deviation (19.49 units).

In summary, using the R/S method to obtain the Hurst exponent are shown in Table 6. The value of the Hurst exponent for defective collection process (0.6481) suggest persistence. The value of the Hurst exponent (near 0.5) suggest a random behavoiur for the inbound and outbound repair.

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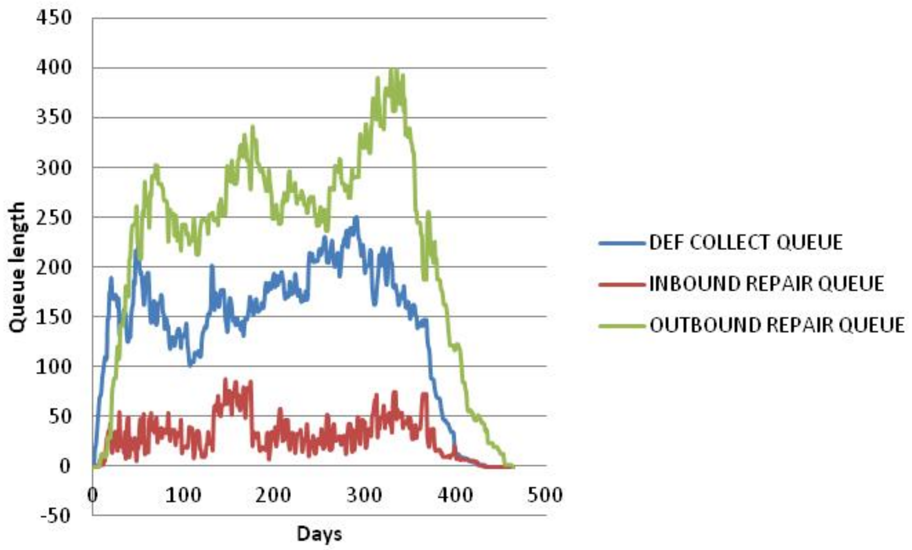

Figure 10. Queue of parts waiting to be processed in each echelon.

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 1 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 collection process, inbound to repair process, and outbound process.

8. Conclusions and recommendations

Some conclusions are:

The systems science perspective provides a framework to better comprehend the supply chain management system. This approach describes how to equate the VSM and ERP to the case of an OEM's SC of a telecommunications firm. The bullwhip effect is a phenomenon experienced by supply chains when demand at the top tends to exhibit more variability than demand at the bottom.

Some recommendations are:

1. Improve trust and reliability of communications between the components of SC.
2. Implement ERP modules in the suppliers and customers information systems.

3. Train suppliers and customers in the basic modules of ERP: MPS, MRP, BOM, IM, CRP, DRP and S&OP

4. Some future researches could be included knowledge of system dynamics, complex systems and others systems concepts to improve understanding and diagnosis of systems.

Annex 1

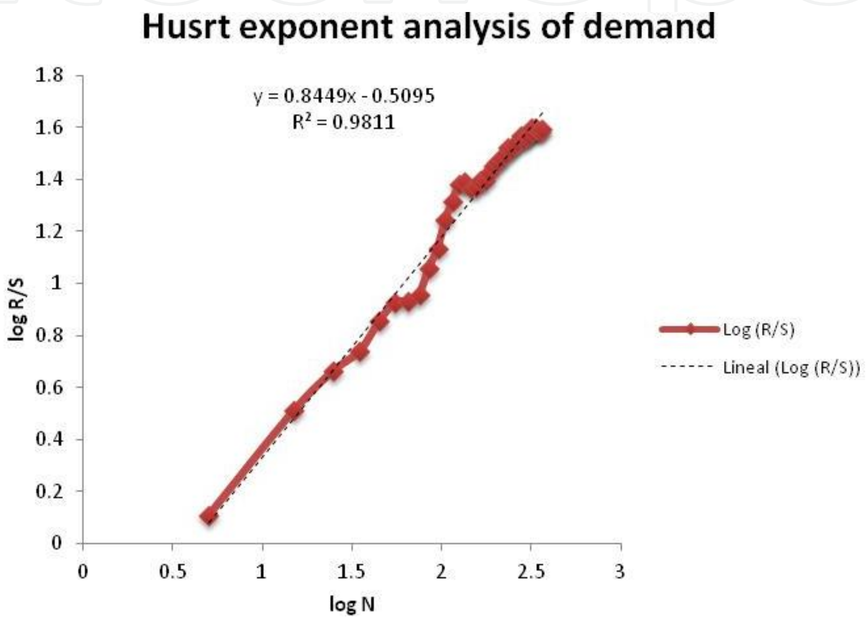

Figure 11. R/S analysis of demand data (H=0.8449).

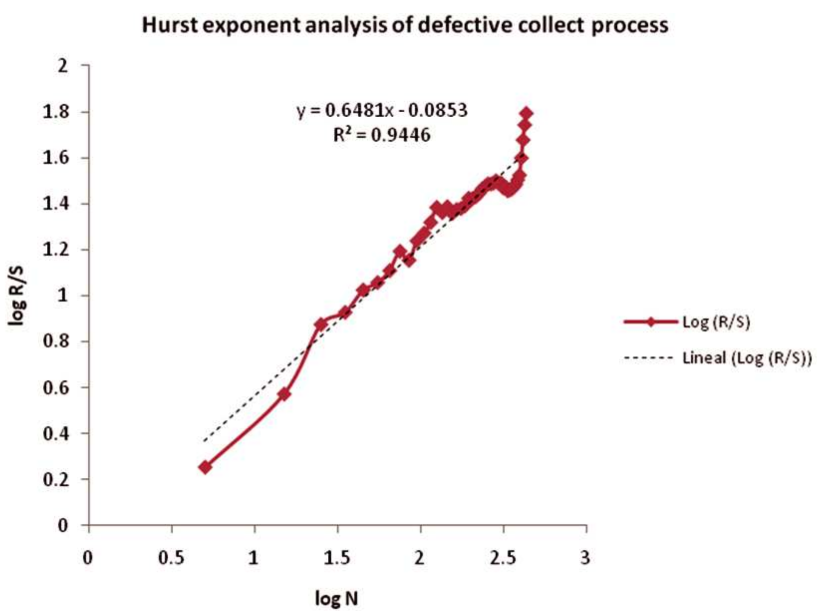

Figure 12. R/S analysis of defective collection process data (H=0.6481).

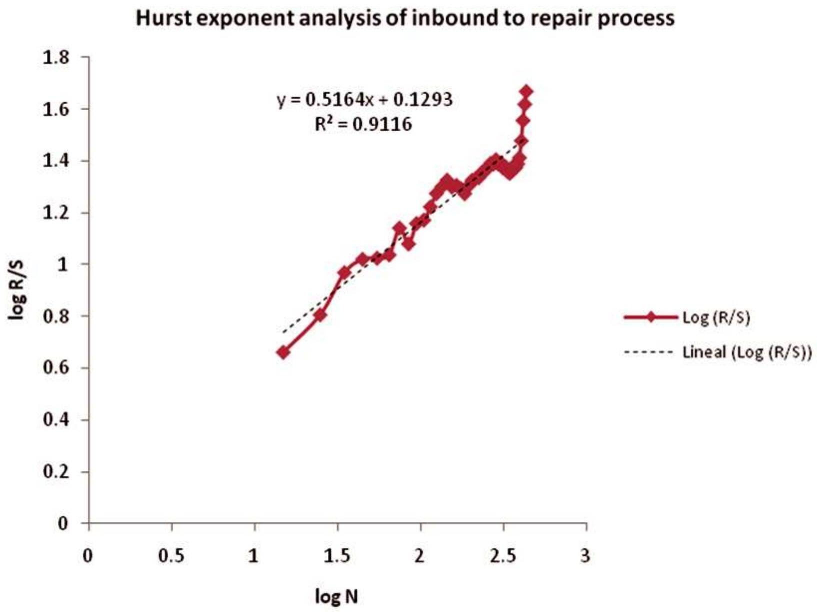

Figure 13. R/S analysis of inbound to repair process data (H=0.5164).

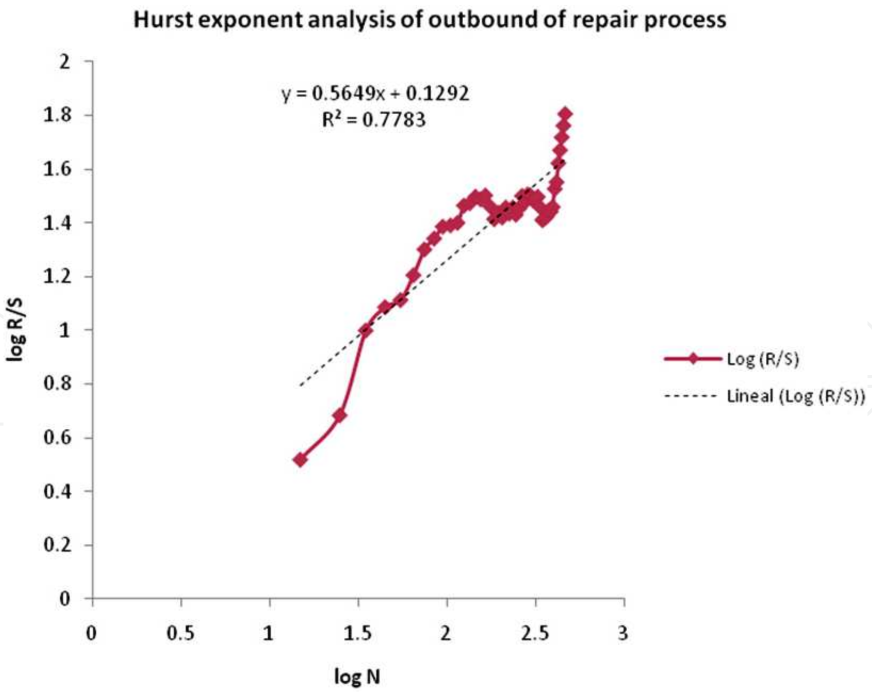

Figure 14. R/S analysis of outbound of repair process data (H=0.5649).

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