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# **A Complex Adaptive System Approach on Logistics**

- Implications of adopting a complexity perspective

Thesis for the degree of Licentiate of Engineering

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Department of Design Sciences  
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Lund University 2003

A Complex Adaptive Systems Approach on Logistics - Implications of adopting a complexity perspective

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Lund, April 2003

Fredrik Nilsson

## **Abstract**

The quest of developing the logistics discipline, with a more theoretical foundation, is something several authors have emphasized and called for. Today one could argue that most of the research on logistics has a strong connection to the positivistic paradigm where there is a great emphasis on prediction, rationality and control in the solutions produced. In order to challenge the common assumptions and develop the logistics discipline, the process of knowledge creation i.e. the epistemological considerations, are central. Since a paradigm consists of metatheoretical assumptions i.e. ontology and epistemology, the paradigmatic question is the key in order to change the frame of reference of the logistics discipline.

The overall purpose of this licentiate thesis is to propose a paradigmatic view and a pragmatic approach based on the science of complexity that contribute to the further development of the logistics discipline.

Two main methods have been used; one focusing on my main research method, which is my study of literature related to the field, and the other on the empirically oriented case studies that have been conducted

The paradigmatic view proposed in this thesis is based on insights gained from the science of complexity. Assumptions made concerning how to approach and transfer knowledge attained from our perceived reality, drive the choices of methods when conducting research and have, of course, great influence on the results obtained and presented from any research process. Adopting a complexity perspective means taking a step away from the common positivistic influenced view, which dominates the logistics discipline, and approaching the phenomena of interest with a different set of assumptions and prerequisites in the research process. This set of assumptions is in line with the complex adaptive system (CAS) platform developed in the thesis. The CAS platform is the foundation for the proposed pragmatic approach. The first properties of the proposed platform i.e. the CAS feature covering internal properties, are of central importance in order to grasp fully the complexity of a studied system and to understand where it is derived from. The proposed pragmatic approach means

taking into consideration the smallest elements of, and agents relevant to, the study being conducted.

From this internal approach the mindset of the researcher or practitioner is of great importance in the event of what such an approach might reveal about the problem being studied. In order to capture emergent phenomena and identify self-organization on different levels of description, we need a perception of the context as being “gray”; that is not considering the context as something which is static or stable, nor as something totally disoriented and uncontrollable.

The metaphorical description of a fitness landscape where coevolution and continuous changes caused by the actions performed by agents inside and outside the perceived system under study, could be beneficial in the research process. This is the case since too many reductions of various factors could result in “far-from-reality” based solutions.

The fundamental aspects of the pragmatic approach are a bottom-up perspective, where the smallest elements relevant to a certain logistics problem are considered, the system built up from this and, of course, an alignment with the paradigmatic view based on the science of complexity.

**Keywords:** complex adaptive systems, complexity theory, epistemology, logistics, logistics systems, paradigm

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## 1 Another Research Agenda

The quest of developing the logistics discipline, with a more theoretical foundation, is something several authors have emphasized and called for (Arlbjørn & Halldorsson 2002;Dunn & Seaker 1994 ;Garver & Mentzer 1999;Mentzer & Flint 1997;Mentzer & Kahn 1995). Garver and Mentzer (1999 p.33) state, for example, that “*researchers are calling for future logistics research to have a stronger theoretical foundation*”, while Kent Jr. and Flint (1997 p.6) argue in their discussion concerning the future development of logistics that “*another future focus is likely to be theory building.*” However, the aim of this theoretical development of the logistics discipline, nevertheless, differs from author to author. There are indications of a striving towards a theory based on positivistic or postpositivistic-oriented epistemology, which Mentzer & Kahn (1995), Mentzer and Flint (1997), and Garver and Mentzer (1999) represent first and foremost. At the same time, authors such as Mears-Young and Jackson (1997) as well as Arlbjørn and Halldorsson (2002) are asking for challenging paradigms for research conducted in the logistics discipline.

Nevertheless, today one could argue that most of the research on logistics has a strong connection to the positivistic paradigm (Mentzer & Kahn 1995) where there is a great emphasis on prediction, rationality and control in the solutions produced. The overall beliefs of designability, planning, and control are promoted to a great extent. For example, in the often-cited definition of logistics management provided by CLM ([www.clm1.org](http://www.clm1.org)<sup>1</sup>), it is stressed that logistics management is about planning, implementation and controlling of logistics activities. Nonetheless, Arlbjørn & Halldorsson (2002 p.22) question this single paradigm by stating: “*if we take this view for granted, we may produce a unilateral view of logistics knowledge that only focuses on objective and observable phenomena.*”

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<sup>1</sup> March 2003

The logistics discipline may be regarded as functionalistic<sup>2</sup> (Mears-Young & Jackson 1997). Consequently, since the logistics discipline is first and foremost an applied research area, and most of the research conducted concerns problem-solving methods related to industry, the paradigmatic foundation in logistics has not been challenged to any great extent. However, as Guba and Lincoln (1998 p.195) state: “*questions of methods are secondary to questions of paradigm.*” Morgan (1983 p.14) adds that if the problem contexts are viewed from different paradigms we can “*see and understand how we can research organizations (and any other aspects of social life) in ways that tell us something new about the phenomenon in which we are interested.*” In other words the logistics discipline might benefit from a paradigmatic discourse, in order to further develop logistics research approaches and the knowledge that is produced.

In order to challenge the common assumptions and develop the logistics discipline, the process of knowledge creation i.e. the epistemological considerations, are central. Arlbjørn & Halldorsson (2002 p.31) address the process of knowledge creation on three different levels (see figure 1.1), the practice level, the discipline level, and the meta level.

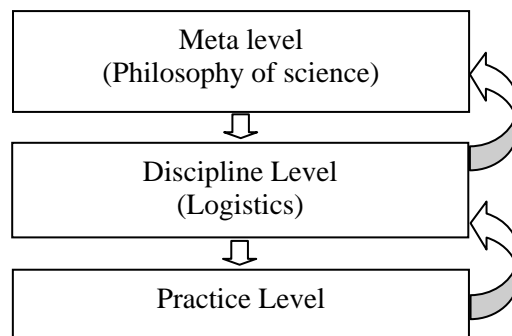


Figure 1.1. The interplay between the levels of practice, discipline, and philosophy of science. Modified from Arlbjørn & Halldorsson (2002 p.31).

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<sup>2</sup> The term functionalistic is derived from Burrell and Morgan (1979) and is one of the paradigms they use in the analysis of social theory. They (ibid. p.25) state that the functionalist paradigm “*represents a perspective which is firmly rooted in the sociology of regulation and approaches its subject matter from an objectivist point of view.*”

The practical level, starting from the bottom, concerns the actual logistical work being accomplished in day-to-day operations. The discipline level is where the majority of the logistics-related research is focused. It is on this level new logistics methods are developed; either from research with an empirical focus, where best practice solutions are reported and “glory stories” (New 1996) presented, or as theoretical borrowing from other theories (Stock 1997). The final level, the meta level, is where the ontological and epistemological debate is centered and thereby lies as the foundation for the paradigm the logistics researcher belongs to. According to Burrell and Morgan (1979) a paradigm consists of meta-theoretical assumptions. This means that the paradigmatic question is the key in order to change the frame of reference of the logistics discipline.

A paradigmatic discourse may benefit the logistics discipline by increasing our consciousness of *why* we as researchers do the things we do and *how* we do them. When we enter a research field the common assumptions and beliefs existing in the community are transferred, in explicit as well as implicit modes, and eventually taken for granted (Kuhn 1996). Kuhn (1996, p. 46) states:

*“Scientists work from models acquired through education and through subsequent exposure to the literature often without quite knowing or needing to know what characteristics have given these models the status of community paradigm.”*

Mears-Young and Jackson (1997) claim that it might be useful and beneficial for logistics researchers to be more self-reflective about what foundations the methods and provided solutions stand on and the implications this implies. Powell (2003, p.286), with relevance to the suggested paradigmatic discourse, states, *“for any empirical discipline, epistemological beliefs have theoretical and methodological consequences, and habitual beliefs can lead to dogmatism, illusion, or despair.”* In other words, the ontological as well as the epistemological assumptions need to be reconsidered, since the question of how objective the research conducted and the results presented could be, depends on these assumptions.

Ontological assumptions are assumptions about reality, and, as Guba and Lincoln (1998) argue, the ontological questions concerning our view of reality are the first to be asked when a paradigm is discussed. The next question, suggested by Guba and Lincoln (ibid.) concerns knowledge and, as Burrell and Morgan (1979 p.1) state, is thereby *"about how one might begin to understand the world and communicate this as knowledge to fellow human beings."* These assumptions have direct implications for the methodology and methods used (ibid. p.2) and thereby constrain the basic beliefs taken for granted during the research process.

### **1.1 Knowledge and Prediction**

The reductionistic assumptions concerning the possibility of reducing complexity and quantifying it by separating parts or problems into simple elements and sub-problems lay as the foundation for the positivistic paradigm (Goodwin 2000). Kauffman (1995a p.VII) states that *"the past three centuries of science have been predominantly reductionist, attempting to break complex systems into simple parts, and those parts, in turn, into simpler parts."* This implies an approach where an identified phenomenon is broken down into solvable parts, and where the parts, after being scrutinized, are placed together into a solution in a summative manner. With such an epistemological assumption in mind, *"better management is often seen as simply running the "machine" faster or more efficiently."* (Allen 2000a p.1) In management jargon this epistemological assumption could be regarded as top-down-oriented and as I have interpreted it, the rule in the logistics discipline. This top-down approach could be exemplified by a statement provided from Van Ackere, Larsen, & Morecroft (1993 p.413) where they discuss business process reengineering, and declare that *"this approach initially analyses an issue at a very aggregate level, every element of the process being represented as either a stock (accumulation) or a continuous flow. ... This analysis can yield considerable insight into the process. Once the process as a whole is well understood, one can dig deeper into specific aspects of the process."*

However, while this reductive top-down oriented process suits various problems where reductionism can be assumed very well (Dent 1999), it may not always benefit

the result if the phenomenon under study consists of interdependent parts that are hard or impossible to unravel, i.e. problem situations where context and phenomenon are complex. Allen (2000b p.79) addresses two basic reasons for the complexity perceived in a given situation. Either the complexity is the result of many interconnected parts where the connections are known, or it is the outcome of non-linear interactions with bifurcation points that may result in a multitude of outcomes based on creative and surprising responses. Complexity of the first kind only needs more computer power to unravel it while the second type needs novel views and approaches that the positivistic paradigm cannot contribute.

Another tread in the positivistic paradigm, based on the successful reductionistic approach (Kauffman 1995a) in foremost physics (Gell-Mann 1994), is the identification of knowledge strongly connected to prediction. This focus on prediction has led to influences on other fields, for example logistics, where methods such as planning and forecasting are profoundly emphasized. However, knowledge in this sense could also be interpreted as whether or not a phenomenon can be predicted. Knowing when it is impossible to predict is also knowledge (Allen 2000b). This gives the epistemological discussion another dimension, a dimension that may benefit new approaches to the development of logistics.

## **1.2 Assumptions in the Simplification of Reality**

Allen (2000b p.80) makes a list of ontologically as well as epistemologically related assumptions identified in the process of reducing complexity to simplicity. He points out five steps starting from “reality” down to equilibrium models in this simplifying process, and the steps are as follows (see table 1.1):

## Another Research Agenda

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*A1. We can define a boundary between the part of the world that we want to "understand" and the rest. In other words, we assume first that there is a "system" and an "environment."*

---

*A2. We have rules for the classification of objects that lead to a relevant taxonomy for the system components, which will enable us to understand what is going on.*

---

*A3. The third assumption concerns the level of description below that of the chosen components or variables. This is a simplification of reality that fixes the nature and the responses of the underlying elements inside the components. The elements are "homogeneous."*

---

*A4. The fourth assumption is that the individual behavior of the subcomponents can be described by their average interaction parameters.*

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*A5. A fifth assumption that is often made in building models to deal with "reality" is that of stability or equilibrium.*

---

Table 1.1. Assumptions considered in the reduction of complexity to simplicity (Allen 2000b p.80).

Discussing the implications of making these assumptions and exemplifications of their use in the logistics discipline are the next steps in this thesis. Initially considering all the assumptions, A1 to A5 in table 1.1, leaves us with positivistic logistics research. Making these assumptions means that stability and equilibrium represent an optimal state to strive toward and that this is possible since reduction of uncertainty balances the demand and supply of products. This type of reasoning i.e. a striving towards equilibrium and stable states together with reductions of uncertainty, is apparent in the logistics discipline, which both Lambert, Stock and Ellram (1998 p. 453) emphasize by declaring that "*an effective organization must exhibit stability and continuity,*" and Lambert and Cooper (2000 p.72) state: "*controlling uncertainty in customer demand, manufacturing processes, and supplier performance are critical to effective supply chain management.*" The use of linear programming to optimize

resource allocations in supply chains is a good example of an applied method which is widely used in the practice of logistics. According to Shapiro (2001 p.85), there are five fundamental properties accepted in linear programming. These are: 1) linearity 2) separability and additivity 3) indivisibility and continuity 4) single objective function, and 5) data known with certainty. The great advantage of linear programming is of course the simplicity of using it. However, it might not represent many of the problems and situations we are affected by in the logistics discipline. To summarize then; assuming all the assumptions, A1 to A5, represent assumptions and beliefs concerning a predictable future, where someone has the ability to deliberate design and amend the system towards a chosen goal and this can be done without any thoughts about the history related to the problem (Allen 2000b).

Making the assumptions A1 to A4 correspond to the positivistic side of the systems approach, which could be compared to what Checkland (1993) defines as the hard systems approach. Non-linearity is here accepted since concepts such as positive and negative feed-back (Ashby 1956), together with the Aristotelian phrase “the whole is more than the sum of its parts” (Von Bertalanffy 1969), are introduced. System dynamics, another commonly used tool and methodology in the area of logistics (Forrester 1995;Forrester 1998;Lee, Padmanabhan, & Whang 1997;Schwaninger 2001), represents a mechanical representation of changes observed in logistics, however, equilibrium is not assumed (Allen 2000b). Instead of a single future equilibrium, system dynamics models can reach different types of equilibria, stable or unstable in their nature. System dynamics still represents a deterministic mechanism since the underlying events forming the properties of the whole are represented by their average (ibid.). No heterogeneity is considered among the individual events or parts in the systems. In summary, by making assumptions A1 to A4 the researcher also assumes predictability and intervention in the systems under study. Neither has any consideration been taken regarding the history related to the studied phenomenon.

The next step, once assumptions A1 to A3 have been made i.e. there is a “system” and an “environment,” there are rules for the classification of objects, and the elements constituting the systems components are homogeneous, is where self-



organizing dynamics is introduced. By making these assumptions, the prediction of the system under study is limited to probabilistic patterns of behavior on different levels of description. The behavior of individual events is considered, and according to Allen (2000b p.85) this gives “*the system a collective adaptive capacity corresponding to the spontaneous spatial reorganization of its structure.*” This means that the parts within the system can change the system structure. The consideration given to the parts in the system separates the self-organizing approach from system dynamics. The ability to reconfigure the system from the outside is also at this stage probabilistic, i.e. influences from the outside can affect the system but what outcome it will produce will only be revealed over time. The link to logistics is now harder to make since tools or methods based on only these assumptions are limited. However, the work carried out by Biosgroup ([www.biosgroup.com](http://www.biosgroup.com)), using self-organizing ant-algorithms in the models used, suits this approach. Positivism can still be revealed since there is an underlying belief that identifiable rules can be found in the system, i.e. some master rules that have a major influence on the whole system. A commonly referred example is Reynolds (1987) “boids” program. The program is capable of simulating flocking behavior, similar to that of birds, by only using three simple rules. These are: a) maintain a minimum distance from other objects and boids in the environment, b) match velocities with other boids in the neighborhood, and c) move towards the perceived center of mass of boids in the neighborhood.

Presupposing only the first and second assumption (A1 and A2), Allen refers to such systems as being evolutionary complex systems. Here we are still talking about systems and their environment, but the events or actors in the self-organizing approach<sup>3</sup> are now considered as learning or adaptive agents. This means that not only are the structures and behaviors in the system aggregated from the heterogeneous group of agents on a lower level of description transformed, but also the agents transform themselves as time goes by. Allen (2000b p.88) makes the distinction that “*adaptation and evolution result from the fact that knowledge, skills,*

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<sup>3</sup> see previous paragraph

*and routines are never transmitted perfectly between individuals, and individuals already differ.*” In other words, thanks to differences, disagreements, and conflicts adaptation and evolution can take place. I have not been able to find any examples from the literature on logistics where evolutionary complex system models have been used. Consequently, this could be an objective for future research.

By only taking into account the first assumption (A1), which I refer to as a hermeneutically oriented approach, where reality is considered a social construction that is created by individuals in each moment passing by is to move away even more from the positivistic paradigm. Whether or not an hermeneutic approach, or what Arbnor and Bjerke (1997) refer to as the actors approach, could benefit the logistics discipline is not the task of this thesis to investigate further and the matter will thereby not be considered any more. However, this might also be an interesting area for further research.

Nevertheless, as stated above, in order to develop the logistics discipline towards a more theoretical oriented field, the foundations and underlying assumptions found in the logistics paradigm have to be challenged. In this thesis the foundations of logistics will be challenged by focusing on *why* and *how* research may be conducted when assumptions four and five are not considered. In other words, this is an attempt to move the logistics discipline on the ontological axis toward a more nominalistic view or less positivistic view (Burrell and Morgan 1979) i.e. considering more complexity in the problem situations under study. The reasons for this are several. Firstly, the knowledge produced within the logistics discipline relies heavily on an objective reality i.e. the positivistic paradigm (as discussed above), and as Kuhn (1967) argues, researchers entering a discipline, and thereby a research paradigm, often compel to the common terminology, norms and beliefs provided by people already within the discipline. This means that for researchers not believing in the assumptions associated with a positivistic view finds it difficult to compel. Consequently, researchers either, consciously or unconsciously, begin accepting the common believes and norms, or they change discipline. Secondly, firms have put lot of money, time, and resources into models and techniques that focus on control and prediction and where cause and

effect relationships are established. One example is the business process reengineering movement where radical changes of firms, and even supply chains, are seen as designable from a top-management point of view (Davenport 1995; Van Ackere, Larsen, & Morecroft 1993). However, the results of these efforts are not very impressive. Cao, Clarke, & Lehaney (2001) report that 70 percent of reengineering efforts result in failure. Thirdly, control and predictive assumptions are paramount in the customary literature on management (Lissack 1999) where objective reality is taken for granted and cause and effect relationships are promoted. Consequently, firms' efforts to manage logistics systems and processes have often resulted in frustration and anxiety (Choi, Dooley & Rungtusanathan 2001), not least for the managers who are supposed to be in charge. To summarize, by considering more complexity in the models constructed by researchers as well as managers, our ontological views may change and therefore also the way we communicate our reflections and thoughts i.e. epistemological considerations. And in this process channeling the epistemological considerations into a paradigmatic view where the cause and effect emphasis is set aside and other phenomena such as emergence, non-linearity, heterogeneity, and self-organization are brought into focus.

### **1.3 Towards more Complexity**

As discussed above, in order to disregard assumptions A4 and A5 in Allen's framework there are implications that need consideration when research is being conducted. The concepts of self-organization and evolution are not explicitly dealt with in logistics research and methods and techniques such as systems dynamics and other quantitatively oriented approaches cannot comply with these approaches. However, in the emerging science of complexity these concepts and other related ones, such as emergence and adaptivity, are of central importance and interest. Complexity theory and its paradigmatic foundations will here briefly be introduced and further discussed in the following chapters.

The science of complexity is derived from several disciplines and theories, and as Bar-Yam (1997 p.2) indicates, when knowledge increases as a result of increased

perceptual complexity, areas diverge into theories and disciplines of their own and focus is increasingly placed on more details. The science of complexity designates another perspective in trying to find universal properties among several disciplines and thereby unifies knowledge and perspectives on reality between different theoretical areas. *“The study of complex systems focuses on understanding the relationship between simplicity and complexity.”* (Bar-Yam 1997 p.293) In that sense, it may be regarded as a truly interdisciplinary science.

While the characteristics described for complexity theory might seem closely connected to the general systems theory (Von Bertalanffy 1969), cybernetics (Ashby 1956; Beer 1959), system dynamics (Forrester 1995), and the systems approach (Checkland 1993), several differences identified when we examine how the complexity theory impacts on research approaches and assumptions. One apparent difference is that *“one of the basic premises of complexity theory is that much of the apparently complex aggregate behavior in any system arises from the relatively simple and localized activities of its agents. Systems theory, on the other hand, defines complexity as arising from a high number of parts (agents) and interactions.”* (Phelan 1999 p.239) Another, difference is the emphasis on time and change in complexity theory which differs from the systems theory (Choi, Dooley, & Rungtusanatham 2001 p.364).

Nevertheless, the complexity movement is first and foremost an attempt to move science away from the heavily founded thoughts of reductionism and positivism in the majority of disciplines today. From an ontological view the perceived reality is complex i.e. phenomena, people, artifacts etc. are interwoven and interrelated and the processes perceived are irreversible which denote the important factors of time and change (Axelrod & Cohen 2000; Bar-Yam 1997; Gell-Mann 1994; Kauffman 1995a; Waldrop 1992). The future is mainly viewed as unknown, or, as Prigogine (1997 p.1) states, under *“perpetual construction.”* Choi, Dooley, & Rungtusanatham (2001 p.356) declare that *“in a complex system, it is often true that the only way to predict how the system will behave in the future is to wait literally for the future to unfold.”* It follows from this that the epistemological assumptions associated with the

complexity theory are, to a greater extent, in line with the limitations of handling or even understanding perceived reality. Richardson, Cilliers, and Lissack (2001 p.13) state that “*a principal requirement of a complexity-based epistemology is the exploration of perspectives.*”

#### 1.4 Purpose

I have already opened this thesis by discussing the paradigmatic foundations upon which the logistics discipline stands, and will continue this discussion from an ontological as well as epistemological perspective. This is in order to contribute to the discourse which I believe is needed to further develop the logistics discipline into a more theoretically oriented discipline. Consequently, the purpose of this thesis is stated as follows:

*The overall purpose of this licentiate thesis is to propose a paradigmatic view and a pragmatic approach based on the science of complexity that contribute to the further development of the logistics discipline.*

#### 1.5 Readers' Guidance

After the motivation and background for the purpose stated in this first chapter you, the reader, will now be introduced to the process of describing, discussing and, of course, fulfilling the stated research purpose. This process will start off in the following chapter, **The Paradigmatic View**, where the science of complexity is introduced more thoroughly. Central concepts from the science of complexity such as self-organization, emergence, adaptation, and complex adaptive systems are described. The purpose of the chapter is to present the complexity theory and the paradigmatic implications derived from it, which will be the foundation for the third chapter, **The Pragmatic Approach**, where the discussion is transformed into a pragmatic argumentation. The pragmatic approach is described as being on the logistics disciplinary level<sup>4</sup> whereat the discussion will aim to identify how the

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<sup>4</sup> see figure 1.1 on page 2

foundations from science of complexity discussed in the paradigmatic approach will impact on research and concepts in the logistics discipline. This means, as described above, that assumptions four and five in table 1.1 are disregarded and a more complexity oriented approach to deal with logistical issues will be introduced. Chapter four, **Research Process**, is a reflection and discussion of what methods I have used and major steps I have taken. Following the first three chapters, a final discussion and concluding remarks, as well as contributions and suggestions for further research, will be presented in the final chapter, **The Alternative Research Agenda**.

The thesis has been produced as a collection of papers and these are to be found in appendixes 1-3. These first four chapters act as an interconnecting framework that connects the papers and that forms the whole, which is more than the sum of its individual parts. The arguments, context and conclusions from the papers have been integrated into the text. This is in order to benefit the reader as much as possible in his/her understanding of the reasoning and arguments provided both in the papers and in the cape.



## 2 The Paradigmatic View

In the third paper<sup>5</sup>, it is concluded that a modified version of the often-cited definition of logistics management, provided by the Council of Logistics Management, is needed. This because, as a result of continual reinforcements of already established assumptions within the current positivist-influenced paradigm, novel perspectives are restrained and ignored, and this restrains further development of methods and solutions in the logistics discipline. The version called for in our paper is one that considers the apparent phenomenon of self-organization as well as emergence in the process of controlling, implementing and planning logistics processes. While one could argue that this change in the definition of logistics management will not be a paradigmatic change, it might provide a perspective to the paradigmatic discourse that may benefit the further development of the logistics discipline. Ontological as well as epistemological considerations i.e. changes of paradigmatic views might reveal new approaches and novel results or as Dent (1999 p.12) describes it “*how we see things determines much of what we see.*” Moreover, as Lissack (1999) emphasizes, the language being used in a discipline or a firm reflects how reality is conceived, and this limits the possibilities available for the members to improve their mutual understanding as well as to improve solutions to various problems both within the discipline and within firms.

The paradigmatic view proposed here is based on the complexity theory. Consequently, the first part of this chapter will describe and discuss the science of complexity and how it is suitable as a paradigmatic view proposed by the author. The discussion will terminate in the introduction and description of complex adaptive systems, which will serve as the theoretical foundation to the following chapter, the pragmatic approach. Complex adaptive systems are a special kind of complex

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<sup>5</sup> see appended papers, paper three



systems that are characterized by their ability to act, react, and adapt to perceived changes in their surroundings.

A common mistake and misinterpretation I have countered encountered during my research process is the assumption that complexity theory is synonymous with chaos theory. Appendix one is therefore especially assigned to straightening out this misinterpretation.

## **2.1 The Science of Complexity**

In his book, *The Quark and the Jaguar*, Murray Gell-Mann (1994 p.218) writes about disorder as a natural state in systems;

*“The explanation is that there are more ways for nails or pennies to be mixed up than sorted. There are more ways for peanut butter and jelly to contaminate each other's containers than there are to remain completely pure. And there are more ways for oxygen and nitrogen gas molecules to be mixed up than segregated. To the extent that chance is operating, it is likely that a closed system that has some order will move toward disorder, which offers so many more possibilities.”*

The quotation above might reveal some of the fundamental thoughts common in complexity theory. Complexity is something we cannot foresee since there are a greater number of states in disorder than there are of those in order. In addition to this, Bar-Yam (1997 p.1) states that *“it is because we cannot describe the whole without describing each part, and because each part must be described in relation to other parts, that complex systems are difficult to understand.”* However, the problems connected with complexity do not stop there because this knowledge has to be infinitesimally accurate, and because the vast majority of all phenomena taking place are irreversible i.e. time has a direction and the past cannot be relived (Prigogine 1997). This increases the impossibility of controlling any system and predicting its future. Consequently, for us to understand and be able to know anything is certain, the phenomenon under study has to be viewed from a retrospectpective, and even then the knowledge and understanding introduced are a subjective or intersubjective interpretation of something that has already happened. Such interpretations of

phenomena have epistemological implications concerning the types of methods used in research and what results that can be stated based on a research investigation. Complexity theory provides in this context an alternative perspective and in order to give the reader a proper foundation of what is included in complexity theory central ideas and concepts will be discussed.

The ideas and concepts that have appeared in the science of complexity have various applications and points of origin, and these ideas are continually being developed in several areas within natural sciences as well as in areas related to social sciences. These areas are in natural science, for example; physics (Gell-Mann 1994;Prigogine 1997;Prigogine 2002), biology (Kauffman 1995), mathematics (Casti 1995), computer science (Axelrod 1997;Holland 1998;Wolfram 2002), and in social science; economics (Arthur 1996;Kauffman & Macready 1995), business management and strategy (Axelrod 1999;Beinhocker 1997;Beinhocker 1999;Pascale, Millemann, & Gioja 2000;Pascale 1999), organization theory (Morgan 1997;Stacey 1996;Stacey 2000;Stacey 2001), social networks (Epstein & Axtell 1996;Jin, Girvan, & Newman 2001).

Central concepts from the science of complexity that are treated more or less in each of these disciplines and theories are self-organization, emergence, and adaptation. These central concepts will briefly be described and discussed and thereafter a fourth commonly referred to concept in complexity theory will be introduced, namely complex adaptive systems. The concept of complex adaptive systems unifies the earlier concepts and exemplifies these. It also serves as a unifying bridge into the following chapter where the paradigmatic view will be brought to a logistics disciplinary level<sup>6</sup> with pragmatic implications.

### **2.1.1 Self-organization**

*“The maintenance of organization in nature is not – and cannot be – achieved by central management; order can only be maintained by self-organization. Self-*

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<sup>6</sup> The disciplinary level is referred to the description provided in figure 1.1, see page 2.

*organizing systems allow adaptation to the prevailing environment, i.e., they react to changes in the environment with a thermodynamic response which makes the systems extraordinarily flexible and robust against perturbations from outside conditions. We want to point out the superiority of self-organizing systems over conventional human technology which carefully avoids complexity and hierarchically manages nearly all technical processes. ... The superiority of self-organizing systems is illustrated by biological systems where complex products can be formed with unsurpassed accuracy, efficiency and speed.” (Biebracher, Nicolis, & Schuster 1995)*

As discussed in the introduction<sup>7</sup>, self-organizing systems are systems where considerations are taken as to the smallest elements relevant to the study of a certain phenomenon. This means that instead of the traditional approach where average values assumed for parts in a system and where the dynamics is a result of structural issues and impacts derived from the environment, the heterogeneity of that system is assessed and the dynamic behavior derives from the interactions of the heterogeneous parts constituting the system under study. In other words, considering the elements in the systems and the self-organizing behavior is to move away from black-box assumptions where the dynamics is a result of the inputs to and outputs from the system. In contrast, dynamic behavior is a result of what happens within the black boxes. Based on this perspective of interactions within the system creating much of the dynamic behavior, one could argue that in these systems the dynamic processes are results of evolutionary impacts i.e. natural selection as a driver. However, this might not be the whole explanation.

Kauffman (1995 p.I) writes in his book that “*natural selection is important, but it has not labored alone to craft the fine architectures of the biosphere, from cell to organism to ecosystem. Another source – self-organization – is the root source of order.*” He even goes as far as to state: “*self-organization may be the precondition of evolvability itself. Only those systems that are able to organize themselves*

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<sup>7</sup> see pages 7 and 8

*spontaneously may be able to evolve further.*" (ibid. p.185) While evolutionary processes, and especially natural selection, are driven and characterized of competition, the process of self-organization is both cooperative and competitive. Baranger (2000 p.11) goes as far to state that "*once we understand this competition-cooperation dichotomy, we are a long way from the old cliché of "the survival of the fittest", which has done so much damage to the understanding of evolution in the public's mind..*" Marion (in Stacey, Griffin and Shaw 2000 p.139) argues that "*self-organizing interaction intrinsically seeks order,*" in other words, coherent patterns. This order is in Kauffman's view perhaps the origin of life and in several other situations a perceived outcome of dynamic processes. However, this search for order might not always be successful. "*A complex system can self-organize into disintegration just as it can into a rigid, repetitive pattern.*" (Stacey, Griffin and Shaw 2000 p.147)

Bonabeau and Meyer (2001) argue that it is through self-organization that global behavior and/or patterns merge from the interactions individuals make with each other in a local context. Local context refers to connections in either spatial and/or conceptual space. From a rational perspective, i.e. treating human beings as rational in their behavior, self-organization does not exist, since the outcomes of processes and activities are results of design and choices (Stacey, Griffin & Shaw 2000). However, as Fontana and Ballati (in Andersson 1999) argue, self-organization is not a result of individual agents or elements deliberately seeking some kind of order; instead is it the natural result of non-linear actions.

In summary, the phenomenon of self-organizing behavior, which is often observed in every kind of complex system, is important to consider since it explains several situations where the models or predictions made concerning a certain phenomenon do not provide anything substantial. An understanding of self-organizing behavior is beneficial in order to determine the possibilities to control a particular phenomenon. Stacey, Griffin and Shaw (2000 p.155) state that "*when one succumbs to the powerful drive to reduce complexity to simplicity one loses sight of what is so striking about the possibility of self-organizing interaction producing emergent coherence.*"

### 2.1.2 Emergence

*"A theory of emergence would account for the creation of the stunning order out our windows as a natural expression of some underlying laws. It would tell us if we are at home in the universe, expected in it, rather than present despite overwhelming odds."* (Kauffman 1995 p.23)

Emergence could be addressed as the outcome of collective behavior i.e. self-organization of several units, elements or human beings, performing something individually, or together, that creates some kind of pattern or behavior that they themselves cannot produce (Bar-Yam 1997; Goodwin 2000; Lissack 1999). Emergence is commonly referred to as a pattern that can be observed on a higher level of description than the constituting elements being the parts of the phenomenon (Baranger 2000; Gell-Mann 1994; Kauffman 1995a). Baranger (2000 p.9) states that *"a certain behavior, observed at a certain scale, is said to be emergent if it cannot be understood when you study, separately and one by one, every constituent of this scale, each of which may also be a complex system made up of finer scales."* Emergent properties are found in the collective since the parts do not have these properties themselves (Axelrod & Cohen 2000). The concept of the "invisible hand" introduced by Adam Smith in the eighteenth century could be regarded as an emergent concept or phenomenon. Bar-Yam (1997 p.10) provides another example from thermodynamics of two emergent properties, namely pressure and temperature. *"The reason they are emergent is that they do not naturally arise out of the description of an individual particle. We generally describe a particle by specifying its position and velocity. Pressure and temperature become relevant only when we have many particles together."*

Bar-Yam (ibid.) claims that since emergent properties require some effort to understand, both mathematically as well as conceptually, this might be a reason as to why the concept of emergence not has been appreciated or understood to any great extent.

### 2.1.3 Adaptation

In the third paper<sup>8</sup> we argued that adaptation is a central property in what constitutes logistics complexity; perhaps the most central property. The other properties used in the logistics complexity framework, structure and dynamics, which are both highly emphasized in logistics, could be considered as deriving from previous adaptations of former structures and dynamism. This is because structure is a result of earlier adaptations and the perceived dynamics influence the interpretation made by the people experiencing what is happening in the interplay between structure and dynamics. In other words, it is the people's adaptations of how well the dynamics fit into the structures which create changes in behavior and consequently to the complexity within a logistics system as well. This means that adaptation is a central property to consider if logistics processes and systems are to be handled with and understood. This is also the case in complexity theory, where the adaptability of the parts that collectively constitute various systems, makes them complex and interesting.

Adaptation in complex systems can be described as the way individuals, parts, elements, as well as collections of these, in competitive and cooperative ways act on and react to changes perceived in their environments. What this means is that entities adapt to adaptations by other entities in their local context. Here local is referred to physically as well as conceptually and cognitively. Holland states (in Waldrop 1992 p.146) that "*one of the fundamental mechanisms of adaptation in any given system is this revision and recombination of the building blocks.*" This could have a physical as well as conceptual dimension, whereas the former could be the rearrangement of ants in protecting their nest, and the later in thinking in new ways, gaining new perspectives on reality, and thereby adapting to, e.g. the information revolution. Andersson (1999) adds to this the importance of adaptation as being something that has evolved and was not planned especially in environments far from equilibrium and

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<sup>8</sup> see appendix three

stable conditions. Another central feature especially required for populations to adapt is variety within the population (Axelrod & Cohen, 2000). This relies on the argument that variety and heterogeneity represent differences between the capabilities of the elements within the population, which brings new and challenging perspectives to certain issues. This can lead both to conflicts as well as agreements within the population. This adaptive capacity is what Axelrod and Cohen (2000 p.70) address as two-edged and state that “*adaptive capacity can speed extinction as well as increase viability.*” Moreover, in most cases it is difficult to know what the outcome will result in since the rule is that emergent phenomena are highly unpredictable (Kauffman, 1995).

The use of the concept adaptation in this thesis is in line with the constraint Axelrod and Cohen (2000) make; namely that activities and actions aimed at or that may lead to improvement by some means are considered adaptive. This will be more thoroughly addressed in the next chapter.

## **2.2 Complex Adaptive Systems**

Complex adaptive systems are a special kind of complex systems since they have the property of adaptation. As the discussion above pointed out, adaptation means that the agents or elements in the system are responsive, flexible, reactive and often proactive regarding inputs from other agents or elements that affect them. More generally described, in the words of Choi, Dooley, & Rungtusanatham (2001 p.352), complex adaptive systems “*interplay between a system and its environment and the co-evolution of both the system and the environment.*” Waldrop (1992 p.145) gives several examples of what is referred to as complex adaptive systems; “*in the natural world such systems included brains, immune systems, ecologies, cells, developing embryos, and ant colonies. In the human world they included cultural and social systems such as political parties or scientific communities.*”

The characteristic of any complex adaptive system, and therefore also the characteristic of socially or human related situations, arguably includes two steps in the process of acting, namely:

- Discovering what to do (exploration and evaluation)
- Doing what has been decided (implementation) (Allen 2000a)

Furthermore, as Allen describes, the first step is the outcome of the different agents' interactions (both conceptually and physically) i.e. from heterogeneous actors representing non-average elements. The second is, nevertheless, the collective result of the transformed and emergent behavior, which could be seen as an average. Allen (2000a p.2) states "*it is this dialogue between successive "systems" and their own inner "richness" that provides the capacity for continuous adaptation and change.*"

For the further discussion in this thesis, I will present and discuss four features which characterize complex adaptive systems. These are presented illustratively in figure 2.1 and each of these will be described in the coming discussion.

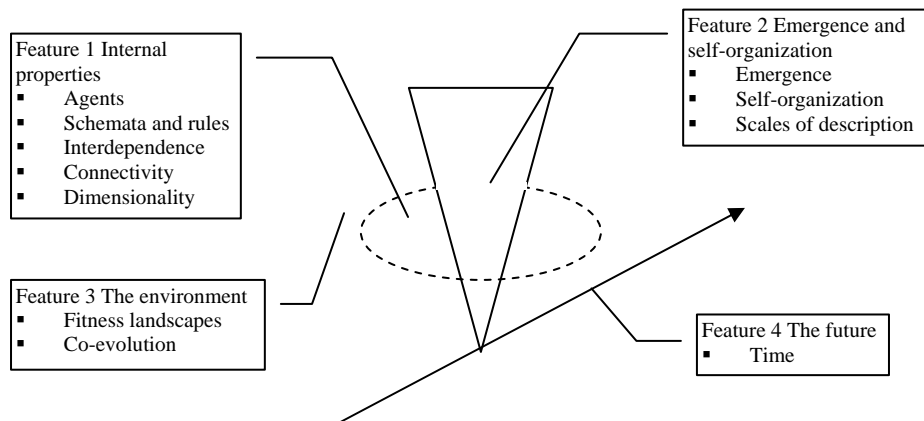


Figure 2.1. Significant features of complex adaptive systems.

The internal properties are what characterize a CAS from the inside i.e. what is taking place among agents and elements within the local context of a studied phenomenon. Emergence and self-organization are special types of features since they occur on different levels of description. This means that through the process of self-organization, different collective outcomes emerge that could be the result of various constellations of interacting agents inside a CAS. The assumption<sup>9</sup> that a system can,

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<sup>9</sup> A1 in table 1.1, see page 6.



to some extent, be separated from its environment is what the third feature is all about. The environment of a CAS both influences the system and is influenced by it. The final feature, the future, emphasizes change and time, and affects all the other features because it makes them dynamic. Together, these features represent what have been interpreted as essential features for complex adaptive systems and in this thesis these features of CAS will be used as a platform for studying logistics systems.

## **2.2.1 Internal Properties**

### **2.2.1.1 Agents**

Complex adaptive systems (CAS) consist of parts and entities normally referred to as agents. In order for complex systems to be adaptive, some of the agents must have the property of agency or adaptivity where agency is defined by Giddens (1984 in Choi, Dooley, & Rungtusanatham 2001, p.353) as “*the ability to interact meaningfully in the course of events.*” These agents act in correlation and interdependence to each other (Bar-Yam, 1997) and facilitate and utilize other parts or elements in their local surroundings. In the context of logistics these agents could be companies, but on a lower level they could also be teams or the people within the organizations.

### **2.2.1.2 Heterogeneity**

The agents are heterogeneous in their behaviors and mindsets. The heterogeneity is the enabler for adaptation of the complex adaptive system. Richardson, Cilliers, & Lissack (2001 p.8) state that in complex systems “*a rich diversity of qualitatively different operating regimes exists,*” which indicates the diversity and variability of CAS, and Allen (2000a) supports this by arguing that creativity and innovativeness are the results of dynamic interactions among diverse individuals i.e. agents. This heterogeneity, which in nature could be addressed as genetic diversity, is essential for species survival. Beinhocker (1999 p.102) states that “*if a species has a diverse portfolio of genetic experiments, and the environment changes and reduces the fitness of typical members, the existence of atypical members, some of whom have a quality useful in the new environment, makes the species’ survival more likely.*”

### 2.2.1.3 Schemata and Rules

The agents in a CAS act according to certain rules or norms, which influence their behavior and thereby also the behavior of other agents at the same time (Axelrod 1999). In other words, they are reacting to changes in their environment simultaneously as they are creating their local surroundings. These rules are often described as schemata where an agent's schema is commonly referred to norms, values assumptions and mental images, which are part of the paradigm i.e. derived and interpreted from the collective of agents. When discussing these schemata several observations have indicated a Pareto principle (Choi, Dooley, & Rungtusanatham 2001) or Power law principle (Kauffman 1995) i.e. some of the schemata identified are more dominant for the collective as well as for each agent, than others. Based on this phenomenon, a CAS is often referred to as being organized according to a few simple rules.

However, sadly enough, the observed phenomenon that CAS are organized according to a few simple rules has led to several normative management writings suggesting implicitly that complexity science opens new doors for control and prediction. The suggested approach is that the manager, making use of complexity theory (or chaos theory<sup>10</sup>), should focus on designing simple rules for his/her employees to follow with the result that the managers obtain the much-wanted control of their businesses (see for example Kupers 2001). There are, of course, several problems linked to such an approach. Firstly, since self-organization is a non-controllable process for any manager and the emerging outcome is unpredictable it cannot work, which is described by Stacey, Griffin and Shaw (2000, p.145): "*if managers are choosing what emerges, then it is not emerging*". Secondly, since the agents are heterogeneous, variations do occur among the schemata observed which may result in totally different scenarios than those which were intended. However, the most fundamental

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<sup>10</sup> At the beginning of the nineties chaos theory was the hot topic for management writers and researchers to use in order to explain almost everything. See appendix one for a more detailed discussion on the limitations of chaos theory and its relation to complexity theory.

problem is related to ontological and epistemological assumptions where this positivistic rule-based approach is just one more of the same in the positivistic paradigm.

#### **2.2.1.4 Interdependence**

The interplay among agents in a CAS is a dynamic process where the influence some agents possess over other agents changes over time (Beinhocker 1997; Pascale 1999; Stacey, Griffin, & Shaw 2000). This means that some agents might have greater influence on the system, and some less, but the interesting part is that no one controls the system. Compared to the brain, there is no master neuron controlling what we think (Waldrop 1992).

#### **2.2.1.5 Connectivity**

In CAS non-linear feedback couplings among the agents connect the agents to each other, where the feedback is both positive and negative in its nature. The agents are limited in the amount of connections they have since they are spatially as well as conceptually limited to a local context. This means that spatially, the agents “*only act on information available in their immediate environments, from those few agents connected to them in a feedback loop.*” (Anderson 1999, p. 222) The conceptual limitations to a local context, refer to the cognitive limitations human beings have in analyzing and synthesizing large amounts of data and information obtained. The issue of cognition related to complexity has been studied by Reeves (1996). Nonetheless, connectivity is of great importance for CAS since it might increase adaptation and as Lewin and Roger (2000 p.26) state “*enhancing interactions leads to the emergence of a creative and adaptable organization.*”

The connectivity in a CAS determines much of the perceived complexity. Axelrod and Cohen (2000, p.26) argue that they expect “*systems to exhibit increasingly complex dynamics when changes occur that intensify interactions among the elements*”. However, as Anderson (1999) describes “*order arises in complex adaptive systems because their components are partially, not fully, connected.*” Systems in which all elements are connected to each other in a feedback loop are

hopelessly unstable (Simons 1996) while too few, strong ties produce overly stable behavior that reduces the possibilities for creativity and learning (Coleman 1999).

#### **2.2.1.6 Dimensionality**

Dimensionality is something Choi, Dooley, and Rungtusanatham (2001) define as the degrees of freedom an individual agent has to carry out autonomous activity. This dimensionality could be seen as a balancing factor between the agents' heterogeneity and the schemas schemata they follow. Here negative feedback acts as a control mechanism and thereby reduces the autonomy of an agent or group of agents. Budgetary systems and company regulations are examples of negative feedback control mechanisms. Norms and common behaviors and beliefs are also of this type, since differing from certain norms or common beliefs can have disadvantageous effects on the agent differing from them. Nevertheless, these control mechanisms have affirmative effects, since too much turbulence may damage a CAS as too much turmoil leaves the agents within disoriented. On the other hand, too much emphasis on control mechanisms and negative feedback hamper the act of creativity and as Kogut (2000 p.415) argues "*too much structure reduces innovation.*" What is needed is positive feedback that reinforces creative movements and amplifies the innovativeness in CAS.

### **2.2.2 Emergence and Self-organization**

#### **2.2.2.1 Emergence**

The type of systems that CAS represents has a common feature; the systems exhibit emergence (Beinhocker 1997; Stacey 2000; Choi, Dooley, & Rungtusanatham 2001). This means that their behavior is unpredictable and often counter-intuitive (Bonabeau 2002) which contributes to a coevolution process among the agents. The created patterns are results of the interaction itself, and no agent can foresee these emergent patterns (Stacey 1996). It also means that new opportunities are always being created by the system. In other words, complex adaptive systems are always in transition. Holland (in Waldrop 1992 p.146) explains that "*it is essentially meaningless to talk about a complex adaptive system being in equilibrium: the system can never get*

*there.*” Equilibrium in CAS equals death (Pascale 1999; Waldrop 1992). Consequently, this means that talking about optimum or optimal solutions in complex adaptive systems might not be beneficial, or as it is described by Holland: *“there’s no point in imagining that the agents in the system can ever “optimize” their fitness, or their utility, or whatever. The space of possibilities is too vast; they have no practical way of finding the optimum. The most they can ever do is to change and improve themselves relative to what the other agents are doing. In short, complex adaptive systems are characterized by perpetual novelty.*” (Waldrop 1992 p.146)

### **2.2.2.2 Self-organization**

It is through the interaction between the agents that emergence occurs, in the process of self-organization (Bonabeau & Meyer 2001). This process of self-organization can only be successful in open systems because of the need of energy (Prigogine 1997). Coleman (1999 p.33) states that *“behavior is self-organizing when people (agents) are free to network with others and pursue their objectives, even if this involves crossing organizational boundaries created by formal structures.”* In CAS self-organization is a powerful drive to make the system robust and adaptive. When self-organization is fully allowed the agents, through their individual actions and interactions with other agents, explore their surroundings and organize themselves into different groups and formations in order to solve problems, implement ideas and, of course, create improvements. Here, one could argue that the self-organizing behavior creates structure, which is both in contrast and complementary to the systems thinking concept that structure drives behavior (Senge 1990). However, as Burkhart (in Andersson 1999 p.225) emphasizes *“a fundamental aspect of complex adaptive systems is that they allow local behavior to generate global characteristics [and structure] that then alter the way agents interact.”* This paradox is central to CAS.

### **2.2.2.3 Levels of Description**

The emergent outcome of the interacting agents or elements results in patterns and behaviors on different organizational levels i.e. the actions performed on a particular

level, with more or less interconnected parts, creating patterns and behaviors on a higher level of description (Anderson 1999). For example, the movement of atoms creates behaviors of cells that collectively form organs. On an even higher level these jointly result in the creation of a human being. Consequently, since CAS are constantly revising and rearranging their building blocks as they gain experience, the organizational levels are also changed as time goes by. As discussed above, this reconstruction of building blocks is the enabler for adaptation.

### **2.2.3 The Environment**

#### **2.2.3.1 Fitness Landscapes**

Since CAS are open dynamic systems that continually exchange information and energy with the surrounding environment (Beinhocker, 1997; Gell-Mann, 1994), a commonly referred to metaphor is the term “*fitness landscapes*.” (Kauffman 1995b; Kauffman & Macready 1995; Levinthal & Warglien 1999; Pascale 1999) A fitness landscape is characterized by its rugged surface, where this surface is the result of the agents acting within the landscape. There are valleys and hills, where a hill represents a high level of fitness and something that the agents strive to reach. However, the agents both react to and create their own environments which causes dynamic behavior that continually changes the surface and thereby the locations of the peaks where a high level of fitness is obtained. This means that even if a high level of fitness is reached at a certain point in time, there is no guarantee that it will be so the next moment in time. Rather, the opposite is true, at least in landscapes characterized by changes and high interconnectivity between the agents. This description and interpretation of the environment an agent is exposed to differ from traditional management metaphors and descriptions such as race metaphors (Lissack 1999). “*In the race metaphor, the landscape is fixed even if the course is not. One has an identified goal and a set of competitors.*” (ibid. p.117) The race metaphor differs very greatly from the fitness landscape perspective where the environment is highly dynamic, where existing competitors change and new entrants emerge spontaneously. Choi, Dooley & Rungtusanatham (2001 p.356) support the critics of traditional

management views and declare that *“in the management and strategy literature and economics literature, an environment is often viewed as a disjointed entity that exists independent of the individual members that reside within the environment. Indeed, as Dent (1999 p.13) proposes “the environment is not “out there,” separate from us,”* instead we are all constructing it through our actions all the time.

### **2.2.3.2 Coevolution**

The term coevolution and its applicability in complex systems is something Kauffman (1995, p.207) addresses and states that: *“An ecosystem is a tangled bank of interwoven roles – metabolic, morphological, behavioral – that is magically self-sustaining. Each organism lives in the niche created by the artful ways of other organisms. Each seeking its own living blindly creates the modes of living for the others”*. Kauffman & Macready (1995 p.27) define coevolution as *“a process of coupled, deforming landscapes where the adaptive moves of each entity alter the landscapes of its neighbors in the ecology or technological economy.”* Similar to ecosystems, each firm or group of firms can be identified in some kind of niche. This niche is a dynamical result of previous actions performed by agents within the firm, as well as actions performed by agents from other firms directly and indirectly connected in some way to the firm.

Kauffman (1995) brings up to mind three stages of laws that within an ecosystem, and for that matter an economic or social system, organize the evolution and self-organization and he especially points to the fact that no *“master choreographer”* (ibid. p.208) exists that control or designs what happens. The first level is the level of the community or the level of the ecosystem, where the behavior of a certain actor, a species or a community of people, creates and is created by the other actors' behavior. From this a specific niche is the outcome after some time has passed. The second level is where coevolution is introduced, since among different species coordinated development that is characterized by both cooperation and competition emerges. An example of coevolutionary patterns can be obtained from the field of population dynamics i.e. the Lodka-Volterra equations, where the dynamics between foxes and

rabbits are described with non-linear differential equations. The focus on the third level is on the evolution of co-evolution, which emphasizes how the fitness of the ecosystem evolves and what implications this has for each species constituting the ecosystem.

## **2.2.4 The Future**

### **2.2.4.1 Time**

A fourth feature of CAS relates to the question of time. *“All complex adaptive systems anticipate the future.”* (Waldrop 1992 p.147) Based on the impressions and information received the agents within the systems generate a set of schemata, and then act on self-modified rules derived from the generated set of schemata. These rules are locally due to the fact that it is the local or closest agents which influence a specific agent most, since there is a limit in both time and space of how much an agent can possibly interpret and understand (Anderson 1999). Holland (in Waldrop 1992 p.147) points out that *“every complex adaptive system is constantly making predictions based on its various internal models of the world – its implicit or explicit assumptions about the way things are out there.”* Added to the agents’ creation of internal models of the world is that complex systems also have a history which influences both their present actions and their anticipations and expectations of the future. As a consequence of the reliability an agent’s history may provide is the fact that history is a limited guide to future behavior. In the process of anticipating the future, agents search for patterns in the past and, as Beinhocker (1999 p.97) declares, *“our drive to see patterns and trends is so strong that we will even see them in perfectly random data.”* This makes the connection to a more subjective or complex ontological view for the complex adaptive system perspective explicit.

## **2.3 The Complexity Perspective**

The paradigmatic view suggests reflecting on the metatheoretical level as to how complexity theory and the concepts described will provide an alternative paradigmatic view, that is, another research agenda. The paradigmatic view is a call for a research agenda, where more complexity is considered in the research process



## The Paradigmatic View

and the solutions provided. The focus is on reconsidering assumptions normally accepted in the logistics discipline that are of a positivistic character, and extending these frames by considering other assumptions and perspectives. The reasons for such an approach are that logistics processes that involve people where the actions these people perform are irreversible, a new research agenda is needed in order for logistics phenomena to be comprehended in an appropriate way. The irreversibility is something Prigogine (1997 p.18) emphasizes, and states that “*nature involves both time-reversible and time irreversible processes, but it is fair to say that irreversible processes are the rule and reversible processes the exception.*” Logistics processes are by nature by the rule rather than the exception.

The complexity perspective i.e. the proposed paradigmatic view based on the science of complexity, is illustrated in figure 2.2. (see below) where the commonly used assumptions in the positivistic view i.e. linear causality, reductionism, determinism, objective reality, simplicity, independence, and command and control, are extended by factors derived from the paradigmatic view proposed in this thesis.

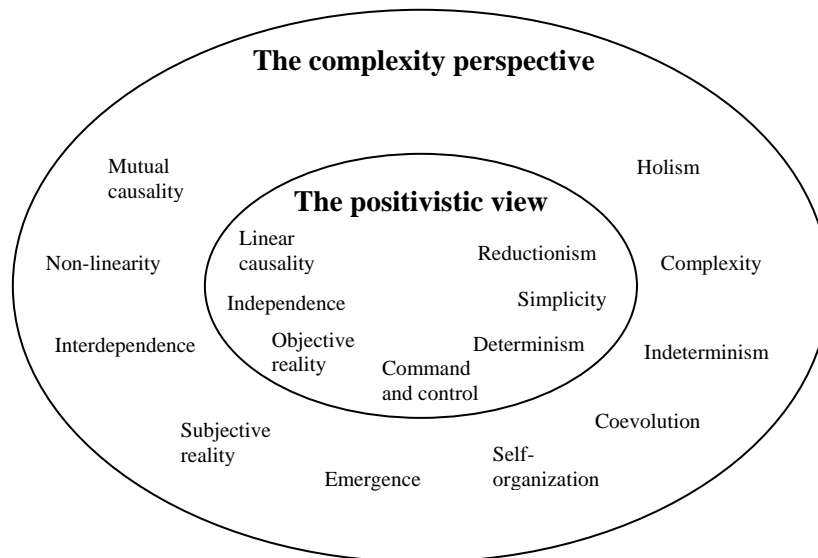


Figure 2.2. The proposed paradigmatic view based on the science of complexity as an extension of the traditional positivistic view, in the logistics discipline. The view is here illustrated in a figure derived and modified from Dent (1999 p.9).

While the positivistic view covers approaches and assumptions that are appropriate to some type of problems, the complexity perspective proposed here as the paradigmatic view, emphasizes phenomena and factors highly apparent in social contexts i.e. in logistics-related areas. These will be described and compared to the positivistic assumptions underlying the bulk of research in the logistics discipline today.

- *Mutual causality and non-linearity.* Instead of linear causality the causes of most problems and issues are of a mutual character since small disturbances can be amplified in non-linear fashions so that there is no interest in finding single factors for complex problems.
- *Interdependence.* Agents and elements used by agents are interdependent and should not be treated as independent since connectivity, even if it is local on the lower levels of description, forms in emergent processes into coherent wholes that connect the activities dispersed agents perform.
- *Subjective reality.* Adaptation is a central feature covered by the complexity perspective and since the agents' actions are results of perceptions of the reality they feel exposed to, this adaptability is a result of their subjective views of reality. This ontological view differs from the objectivistic approach emphasized in the positivistic view.
- *Emergence.* In an objective reality the concept of emergence would not be appropriate to mention since it involves non-reductive patterns which cannot be derived or determined from the agents' autonomous activities, but are still apparent when the collective patterns these agents create together are examined.
- *Self-organization.* The concept of self-organization does not fit into the positivistic paradigm since it does not follow any of the assumptions or factors listed above. From a positivistic perspective, self-organization causes uncertainty and since it cannot be effectively controlled, planned or designed it should be reduced, or even eliminated. However, this process of self-

organization is in several cases the reason for novelty, creativity and innovativeness.

- *Coevolution.* The fact that agents, whether they are seen as people or firms, coevolve causes a number of problems in the positivistic paradigm. Again, coevolution does not fit the deterministic assumptions and the linear causality emphasized in the positivistic view, since it involves non-linear feedback mechanisms, often from a huge number of agents.
- *Indeterminism.* In the positivistic view the emphasis on determinism is the rule rather than the exception. Deterministic assumptions underlie the great emphasis for reducing uncertainty and the focus on actions to improve some identified or conceptualized system in order to reach an optimal state. This differs from the indeterministic approach that is emphasized in the complexity perspective. The focus of the complexity perspective is, in contrast, on exploratory analysis aimed at understanding a certain phenomenon, which helps the people involved to live with uncertainty instead of trying to remove it.
- *Simplicity and reductionism.* From an epistemological point of view, disregarding simplicity as a means for communication of knowledge and instead an emphasis for provision of a complex picture, diverges the complexity perspective from more positivistic assumptions in the act of creation of knowledge described. Complexity could be defined as the amount of information needed to describe or understand something (Bar-Yam 1997). This implies that striving towards simplicity through modeling and explaining certain phenomena in a positivistic manner i.e. by adopting a reductive approach, might, in many cases, result in too great a disregard for information and data to provide a picture which is complete enough to enable comprehension. One example is that the dynamics might not be included in such simplistic descriptions and, as Gillies and McCarthy (2000) hint, the complexity perspective shows that much of our knowledge is focused on

static descriptions i.e. on being, rather than on dynamic processes i.e. on becoming.

To summarize; the paradigmatic view proposed in this thesis is based on insights gained from the science of complexity. As stated in chapter one, the assumptions made concerning how to approach and transfer knowledge attained from our perceived reality, drive the choices of methods when conducting research and have, of course, great influence on the results obtained and presented from any research process. Adopting a complexity perspective means taking a step away from the common positivistic influenced view, which dominates the logistics discipline, and approaching the phenomena of interest with a different set of assumptions and prerequisites in the research process. This set of assumptions is in line with the CAS platform presented and discussed in this chapter.



### 3 The Pragmatic Approach

The concept of complex adaptive systems, described in the previous chapter, will, in the coming discussion, exemplify how the paradigmatic view based on the science of complexity may influence logistics i.e. a pragmatically oriented approach aimed at the logistics discipline. Firstly, the concept of complexity will be discussed in the context of logistics i.e. how complexity is approached and treated in the logistics discipline. Secondly, a conceptual discussion will be presented, concerning whether or not logistics systems can be regarded as complex adaptive systems i.e. the applicability of CAS to logistics systems. This will be achieved by incorporating aspects of the current state of the logistics discipline with the results of, and discussions from, papers one and two<sup>11</sup> and with a case study I have performed. To do this applicability test the four features described as a platform for CAS will be used i.e the internal properties, the concepts of emergence and self-organization, the environment and the future. Finally, the implications the CAS platform may provide when studying logistics systems will be put forward to researchers and practitioners within the logistics discipline.

#### 3.1 The Usage and Handling of Complexity in the Logistics Discipline

Similar to the approach used in paper three<sup>12</sup> this part will start off by using the CLM definition of logistics, and focus will be set on logistics areas that can be derived from this definition. Logistics is defined by the Council of Logistics Management (CLM) as:

*“Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods,*

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<sup>11</sup> see appended papers, papers one and two

<sup>12</sup> see appended papers, paper three

## The Pragmatic Approach

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*services, and related information between the point of origin and the point of consumption in order to meet customers' requirements.*" (www.clm1.org<sup>13</sup>)

It seems quite reasonable to interpret the definition presented above in such a way that it implies a positivistic or at least a post-positivistic approach to the logistics discipline. Consequently, the definition could be interpreted as one in which an underlying belief of objectivity is uppermost, as is the ability of management to plan, implement and control the flow of goods and products, i.e. someone is in the position to control other people and set goals for whole logistics systems and processes. Van Ackere, Larsen & Morecroft (1993 p.413) exemplify the post-positivistic or analytic approach by stating; *"We are all used to the idea that automobiles, ships, aircrafts, office buildings and bridges need careful design to achieve their purpose. But there is much less awareness that business organizations too are 'designable'. This blind spot about business design is all the more surprising when one considers the human and financial costs of a malfunctioning business."*

While the author of this thesis dislike such positivistic beliefs, this observation that researchers and managers believe they can design and control organizations is supported by others, such as Stacey, Griffin and Shaw (2000, p.18), who have observed that *"most managers continue to believe that their role is essentially one of designing an organization and controlling its activities."* However, they (ibid. p.4) also put forward another observation that could be regarded as paradoxical to the belief that managers can design and be in control, because several managers agreed that in their day-to-day operations they were *"the ones in charge but repeatedly finding that they where not in control."* Nonetheless, the common belief of being able to control organizations and, for that matter logistics processes, may not be surprising since being, and acting according to a positivistic paradigm brings assumptions and values that are of a mechanical and deterministic character. Axelrod and Cohen (2000 p.29) provide a good explanation for this mechanical approach when they state: *"No*

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<sup>13</sup> March 2003

*doubt, machines and hierarchies provide easier metaphors to use than markets and gene pools. So it is no wonder that most people are still more comfortable thinking about organizations in fixed, mechanical terms rather than in adaptive, decentralized terms.*” In other words, as emphasized earlier in this thesis, another paradigmatic view is needed in order to move away from simple, reductive, deterministic, mechanical assumptions and to comprehend greater complexity in the study and management of logistics phenomena.

When one continues to analyze the logistics literature and other literature related to the logistics discipline, it is noted that several of the CAS features proposed in the framework are disregarded or oversimplified in numerous cases. For example, the word complexity is often used when describing and discussing logistics, but its meaning and the approaches suggested for dealing with complexity differ not just among the various authors but differ considerably from the CAS platform proposed in this thesis. Usage of the term complexity and the problem of how complexity is handled in the logistics discipline will be explored and discussed in the next section.

### **3.1.1 Complexity in the Logistics Discipline**

*“The complexity of logistics is awesome”* (Bowersox & Closs 1996).

The perception of supply chains and logistics systems as being complex is emphasized by several authors (Bovet & Martha 2001;Bowersox & Closs 1996;Christopher 2000;Cox 1999a;Hagel III 1996;Lambert, Cooper, & Pagh 1998;Lamming et al. 2000;Lumsdén, Hultén, & Waidringer 1998;Rice & Hoppe 2001;Sabath & Dorn-Gorman 2001;Sivadasan et al. 2000;Tan 2001;Tulip 2001). However, how complexity arises is often derived from an interpretation of logistics systems as being hard to understand since these systems consist of a great number of parts, relationships, and flows. This is strongly connected to the emphasis on a holistic view, which, in the CLM definition, is addressed as the scope of logistics processes i.e. from point of origin to point of consumption. From this interpretation, it is quite easy to conclude that by including more activities and processes complexity



increases in the whole logistics system as a result of increased connectivity. However, there are several suggestions on how and why complexity arises in the first place.

Simchi-Levi, Kaminsky & Simchi-Levi (2000) list four major issues causing complexity in a supply chain (or a logistics system):

1. The supply chain is a complex network of facilities and organizations with different, conflicting objectives.
2. The problems of matching supply and demand.
3. The phenomenon of system variations over time.
4. Many supply chain problems are new.

From a CAS perspective it can be argued that the first three issues proposed for the supply chain complexity are surely not the major issues for complexity, instead, they are emergent patterns originating from actions and activities performed by agents. Nonetheless, the proposed issues influence the agents' behaviors and perceptions of their surroundings and are in that sense influential factors on the agents' adaptations to changes in their surroundings. The first issue proposed supports the argument above concerning the fact that complexity as a result of many parts i.e. there is a network of facilities and organizations, which implies a high degree of connectivity. Another notion from the first issue is the emphasis on different and conflicting objectives among the organizations. Even though the emphasis is on a higher level of description, i.e. a firm level, and therefore an emergent pattern originating from agents acting and working together, the notion of conflicting objectives is still interesting since it addresses the heterogeneity found in all complex adaptive systems. The second issue covers the challenge of matching supply and demand. This is linked to the agents' anticipation of the future and complexity might arguably be a result of the agents' willingness to be able to plan and control future events. Again, it is the agents on the lower levels of description who, in their efforts to predict future events, are the factors causing complexity in logistics systems. The notion that systems variations occur over time is a phenomenon that can be observed when studying the data gathered within a logistics system. The system variations in themselves do not cause complexity since agents must interpret these variations in order for them to

influence any system. However, complexity could be seen as resulting from the interactions of agents for whom the fourth reason in the list above, that *many supply chain problems are new*, is the perceived cause in many situations, since context dependence exists for the majority of logistics problems.

Wilding (1998b) proposes three independent but still interacting effects as the causes of complexity in logistics systems. These are deterministic chaos, parallel interactions, and demand amplifications. Once again, these effects are not definite causes of complexity in logistics systems and certainly not independent of each other. For example, deterministic chaos can only be the result of a deterministic approach with deterministic equations. The conditions for such an approach i.e. conditions allowing a deterministic approach cannot be found in logistics systems when people are involved. What could be concluded, however, is that the monitoring of orders received over a certain time may graphically be comparable to the results of deterministic equations resulting in trajectories displaying chaotic characteristics. The second effect, parallel interactions, is in line with a CAS perspective, however, it does not say much about what it is that is acting in parallel. As stated before, complexity arises from agents interacting in several dimensions and this complexity involves their perceptions of these interactions as well. Moreover, since the agents' interactions are the reason for complexity in whatever system is studied, the effects are not independent, but interdependent. Finally, the demand amplifications addressed as causes for complexity in logistics systems, derived in Wilding's text (ibid.) from the bullwhip effect, do not cause complexity, instead, they are the outcome of the agents' perceptions and the associated adaptations the agents make in order to meet the requirements of the customers.

Another approach to, and definition of, logistics complexity is provided by Waidringer (2001). He addresses the complexity in logistics systems which he claims resides primarily in the interrelation of three core properties, namely structure, dynamics and adaptation (Waidringer 2002). While Waidringer emphasizes that these properties are the core of logistics complexity and argues that they must exist together, he differs from the other researchers in the logistics field by proposing that

complexity also resides in what he also defines as extended properties. These are: ignorance, variety, redundancy, uncertainty, entropy, flexibility, resolution, abstraction, demand and goal functions, cognition, connectivity, and size. He summarizes these extended properties of complexity in logistics systems as “*relevant in order to give a complete picture of what make these systems complex.*” By widening the approach to include both the core and the extended properties, the understanding of both the processes and the implications certain changes may have on a logistics system is increased. This position is in line with the paradigmatic view proposed earlier and therefore aligned with the forthcoming discussion concerning the CAS platform’s applicability to logistics systems.

Waidringer (2001 p.115) concludes his argumentation with a definition of logistics complexity:

*“Transportation and logistics systems’ complexity resides in the nature of the structure, dynamics and adaptivity. It is a measure of the possibility of modeling these properties and their dynamic interaction in a way that allows of implementation of control mechanisms, forcing the system under study to meet required service, cost and environmental demands.”*

This definition claims that, based on the measured results of the complexity found primarily in the core properties and their dynamic interaction, a measure of the possibilities of implementing control mechanisms which force a particular system in a requested direction is the outcome. In other words, depending on how complex a system under study is perceived, the possibilities to control it differ.

While this approach is helpful in several ways to determine the complexity and the possibilities to control a logistics system, the issue of how to approach the system under study by using complexity theory is not dealt with to any great extent. How to approach logistics systems by using complexity theory is what the CAS platform in this thesis tries to accommodate. It is proposed in the following discussion that the features of CAS should be used to obtain a more complete picture of certain logistics situations, where complexity could be regarded as high. However, before this can be

achieved, the next, natural step is to perform an applicability test of the CAS platform on logistics systems, before further discussion of the impact a complexity perspective may have.

### **3.2 Complex Adaptive Systems' Applicability to Logistics Systems**

The way this comparison between logistics systems and CAS is conducted is through analysis based on the framework presented in chapter two, which covers the main features of complex adaptive systems. Logistics systems refer to all activities and processes related to the CLM definition of logistics management. That is those concerning scope, focus on efficiency and effectiveness of flows, and for the purpose of conforming to customer requirements. The aim in this part is to provide clearer picture of the commensurability between logistics and CAS. The main claim for this applicability test is: *If the commensurability between logistics systems and complex adaptive systems is high, then research carried out in the logistics discipline would benefit from an emphasis on complexity theory and considerations of the proposed paradigmatic view offered in this thesis.*

For pedagogical as well as illustrative reasons, I will use a case study I have performed to exemplify the different features of CAS. The case study focuses on a concept development called “the invisible journey” where perceived negative aspects experienced by people traveling by air, like waiting time, losses of baggage, etc. should be minimized. This is especially the case for frequent flying people that might gain lots of benefits from minimizing waiting times and maximizing utility when traveling by air. The part my study has focused on is baggage handling i.e. in logistics terms what is possible to achieve in efficiency and effectiveness for the customer as well as other involved parties by using a new baggage-handling concept.

#### **3.2.1 Internal Properties**

##### **3.2.1.1 Agents**

As described above, a central feature of CAS is the emphasis on internal properties and especially the observed phenomenon that it is the agents together create the

perceived complexity in their context. In the field of logistics one could argue with certainty that there are parts or elements which could be regarded as agents. These are the people moving boxes in a warehouse, the managers responsible for replenishment of products, the truck-drivers transporting goods of several kinds, and the people performing planning and forecasting activities, to name but a few. Essentially, this means that it is the agents who directly or indirectly perform the planning, implementation and controlling of logistics processes, as well as the actual performance of the activities being done, whether they are planned or controlled or not. These agents are also characterized by the property of adaptation or agency since their actions or activities are aimed at improvements of their situation as well as the system they identify themselves with. These improvements are in the logistics discipline to make efficient and effective flows that lead to conformity for the customers.

In my case study, there are several types of agents, and these are also on several levels of description. The customer is an agent who initiates the request for his/her baggage to be handled. To transport the baggage from its point of origin i.e. the customer's office or home, to the point of consumption i.e. the final destination, which could be another office or a hotel room, there are several organizations and people involved in the handling process. Here, agents are flight companies, taxi companies, customs, airport control, security firms etc. While these all represent a collective form of agents, the people within these organizations are also agents, and they are the ones really performing the activities.

**Claim 1.** *There are agents with the property of adaptation in logistics systems.*

### **3.2.1.2 Heterogeneity**

The next property for the internal perspective concerns the agents' variability or heterogeneity. The major question is; are the agents showing average behavior or is there heterogeneity among them? In the logistics discipline there are several types of agents, depending on the scale of description, and one could argue that heterogeneity among the agents can be observed on all levels. There are people representing

different areas of responsibility and knowledge in every activity associated with logistics. Naturally, the people themselves also differ in their personal objectives, beliefs, mindsets etc. On the collective level there are different groups or even departments with different goals which also exhibit a great variety in procedures and terminology compared to other groups and departments.

An example from my case study would be one illustrating the difference between two customers, where one wants his/her baggage to be picked up at work but changes instructions at the last minute, whereas another customer keeps to what has been ordered from the beginning. The first customer's change in plans may have effects on the whole performance that day, while the second person's lack of changes does not harm operations.

**Claim 2.** *The agents in logistics systems are heterogeneous, irrespective of what logistics description level is considered.*

### 3.2.1.3 Schemata and Rules

The discussion concerning the schemata or the rules which agents within a logistics context may commonly obey or follow is coupled to the previous discussion about heterogeneity. As concluded above, there is heterogeneity among the agents, however one could argue that there are similarities in the agents' behaviors as well. The question here is on what level of description the variety among the agents' behaviors becomes more dominant than the similarities, i.e. by considering the observed power law principle in CAS where some of the schemata identified are more dominant for the collective as well as for each agent, than others. This is important in order to find the lowest level of description applicable for the purpose of the study. Nonetheless, the quest here is to determine if certain schemata or rules followed by agents can be observed in logistics systems.

Consider the transportation of the baggage from the customer to the airport. The bags or suitcases are going to be delivered at a certain time according to earlier specifications. The agent delivering this shipment will probably use some kind of infrastructure, e.g. a road to drive its vehicle, and if another agents were to replace the

first, the second would probably use the same type of facilitator. In other words, as a cause of limited ways to get to the airport, a schema or rule for the possible delivery routes would be possible to make. However, these two agents could drive at different speeds, which demonstrates the heterogeneity at the same time. There are, of course, several other examples where certain schemata or rules might be observed concerning regulations, security controls, loading capacity etc. However, one should bear in mind that there are always exceptions to schemata and rules as a consequence of unpredictability and the behavior of other agents.

**Claim 3.** *Within logistics systems certain schemata and rules are observable in the agents' behavior.*

#### **3.2.1.4 Interdependence**

In paper one<sup>14</sup> we used the concept of interdependence as a framework for discussing whether or not to outsource. In that paper the concept was split into two parts where the first one relates to the character of the upcoming interactions between the parties in an outsourcing situation. It was labeled interface complexity. The second part is derived from the dependence that becomes highly apparent in an outsourcing situation. This was described as relative power between the parties. The conclusions from the paper reveal the importance these two concepts have for any understanding of what possible scenarios one could expect from an outsourcing decision.

In a logistics context the interdependence among agents, especially when an organizational level of description is examined, is of great importance. Too much interdependence may lead to a state consisting of stability and equilibrium and thereby lead to lock-in effects, while too little interdependence could mean no business at all. This concept of interdependence is similar to other levels of descriptions where interdependence exists among different types of agents.

**Claim 4.** *Interdependence among the agents in logistics systems does exist.*

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<sup>14</sup> see appendix one

### 3.2.1.5 Connectivity

Flows and their management constitute the core concepts of logistics. Gammelgaard (1997 p.16) states, for example, that: “*although the field, in particularly in the recent years, has become very wide, logistics management is fundamentally still about controlling the material flow and how to do it efficiently.*” Arlbjørn and Halldorsson (2002) conclude that the hard core of logistics is flows and point to three significant types of flows in logistics. These are physical flows, information flows and monetary flows. However, these flows are interrupted by different activities, which means that the flows occur between different types of nodes. In other words, connectivity is apparent in logistics systems since nodes are connected by flows. These flows are affected by both positive and negative feedback, which means that connectivity can yield high amplifications, as well as be restricted by control mechanisms. The bullwhip effect is a result of positive feedback, since the feedback amplifies the demand at each node. Truck-loading capacity is an example of a negative feedback mechanism, since there is a limit as to how much can be transported during each delivery.

Nevertheless, logistics flows are complex and challenging in several ways and as previously stated, an increase in degrees of connectivity often leads to greater complexity. Finding similarities in the baggage-handling case study is not a problem here. The case study focuses on one airport and customers from different cities and villages who use the airport for traveling. This means that the connectivity will increase when more locations are included in the pick-up services of baggage. Consequently, this will increase the complexity as well. Another significant connectivity driver is the fact that travelers will be flying to different destinations. Once again, connectivity is apparent in the logistics system.

**Claim 5.** *Connectivity is a central feature in logistics flows, which are the core of logistics systems.*



### **3.2.1.6 Dimensionality**

The dimensionality or the degrees of freedom, which the agents in a logistics system are restrained by, are of several different types. There are physical control mechanisms, ranging from limitations in speed, time and space, which are common to all living beings on earth. However, there are also several types of physical limitations as a result of conscious and emergent standards, such as the measurement of a pallet for transportation. Then there are control mechanisms which regulate everything from handling information and money and legal requirements, to norms and guidelines within firms or groups.

In baggage handling the degrees of freedom for the agents are restricted by several legislative, as well as security-related, regulations and policies. These have recently increased as a consequence of increased terrorism threats and greater competition on the market. These factors have had a great impact on logistics since more tightly controlled baggage handling procedures have been introduced at airports. Nevertheless, regulations on how much baggage weight each passenger is allowed to bring on board have long been in force. This restriction is a result of the maximum weight capacity allowed for the airplanes being used.

**Claim 6.** *Dimensionality is restrained by a great number of different control mechanisms in the logistics discipline but there is still freedom for each agent to influence and act by him/herself.*

## **3.2.2 Emergence and Self-organization**

### **3.2.2.1 Emergence**

The concept of emergence and that of self-organization are what I would argue represent the least understood features or concepts related to CAS in the logistics context. Nonetheless, global properties as a result of emergence are observable in the logistics area even if their origins and appearance are not addressed to a greater extent. Emergent phenomena are results of agents' individual actions, where these actions are forming themselves as a collective into patterns or behaviors that cannot be found when the agents are examined separately. Consider a logistics department,

which is an emergent phenomenon. It may consist of some people (agents) in a management or coordinative position, who monitor performance, receive orders for deliveries, discuss the possibilities to assist new customers etc., and other people performing the actual deliveries, loading vehicles etc. Together they create, in each moment, some part of the logistics system they identify themselves with and this is an emergent phenomenon of agents working; doing many, albeit simple<sup>15</sup> activities.

Another example that is appropriate to the logistics discipline is the focus on processes. Since the business process reengineering movement, focus has been on processes in order to move away from functions and functional silos in organizations. Today, the emphasis on processes and a process perspective is apparent in the whole logistics discipline (Bovet & Martha 2001; Bowersox & Closs 1996; Copacino & Byrnes 2001; Cox 1999b; Lambert, Cooper, & Pagh 1998; Tan 2001). Nevertheless, a process is the result of several parallel and sequential activities or events, i.e. both in space and in time distributed, to produce a coherent outcome. In other words, a process is an emergent phenomenon resulting from agents' actions and activities.

In the case study, emergent phenomena have been observed in several settings in the operations performed. With the introduction of new baggage handling activities, new processes will emerge which are the result of separated but interdependent activities, that is the pick-up at home, the delivery of the baggage to the airport, the handling of the baggage through security to the loading of the airplane, the flight, and the final delivery to the requested destination. Since the range of possibilities for what may happen in these processes is infinite, some outcomes will be unpredictable and have to be handled as they occur, while other aspects are more controllable. Nonetheless, the result is an outcome of contributions from several agents that together form a

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<sup>15</sup> The term simple is here addressed as a relative term to the collective outcome of many agents working together i.e. the collective outcome is more complex than each agents contributions.

whole. The essence from this is a paradox, since the agents are the ones that are fulfilling the purpose and at the same time the ones causing turmoil and complexity.

**Claim 7.** *Emergent phenomena are evident in the logistics context.*

### **3.2.2.2 Self-organization**

What enables emergent phenomena to emerge is the process of self-organization. Local agents, workers in a storage facility, for example, perform their daily operations. What emerges could be norms and rules that reinforce their working behavior and, as they adapt to certain changes caused by themselves or someone else, they may reorganize into small groups and continually improve the usage and capacity of the storage facility. While some manager would probably be rewarded for “planned” improvements, these improvements are with great certainty a result of the interactions of the people involved.

A logistics system is open by nature. There are, for example, exchanges of employees among firms directly connected to a logistics system and among firms identifiable with other supply chains and logistics systems. This could be regarded as a self-organizing process, where the employees have a degree of freedom to explore new opportunities in other industries. In this process energy, knowledge, and information are transmitted and are sometimes regarded as beneficial for all parties. Even within what could be regarded as a logistics system, self-organizing processes are taking place, especially where the degrees of freedom for the agents are high. Structures are frequently created through the creative behavior of autonomous agents working together in the process of self-organization.

**Claim 8.** *Self-organization appears in logistics systems since the agents have some dimensionality and the systems are open by nature.*

### **3.2.2.3 Levels of Description**

The issue of levels of description was dealt with in paper three<sup>16</sup> and will only be discussed briefly here. As stated above, processes are emergent outcomes of the actions agents perform. This could be seen on different levels of description since the agents, who in the logistics context are often people, perform activities dispersed in both time and space. On a higher level of description these activities form into emergent outcomes that can be observed as processes, and by increasing the level of description emergent outcome result in firms and even supply networks. These types of taxonomy are often used in the logistics discipline where different types of processes are subordinated to some departments and collectively are aggregated to a firm level etc. Another example is the hierarchical division of strategically, tactically, and operationally related logistics decisions and approaches.

**Claim 9.** *The discussion of different levels of description is common in the logistics discipline.*

## **3.2.3 The Environment**

### **3.2.3.1 Fitness Landscapes**

The environment a CAS operates in is, as previously stated, often referred to as a fitness landscape. Using this metaphor in a business context, the concept of fitness could be seen as a performance measurement for a firm, a supply chain, or even a manager or any other agent connected to the firm or the supply chain. A high level of fitness means that the overall performance of a specific agent is good e.g. high profitability, large sales volumes, accurate delivery performance etc. In the fitness landscape each agent tries to maximize its own fitness, which means that it tries to find the highest peaks. However, this means that in these attempts to get to the highest fitness peaks the whole landscape changes in structure, since the movements and actions of the agents, both physically as well as conceptually, construct the landscape.

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<sup>16</sup> see appendix three

The effects of one agent's action may in these landscapes spread in non-linear ways, to both local agents as well as to agents far away, both physically and conceptually. While it is reasonable easy to understand the local impacts an agent can provide a considerable amount of research have indicated that impacts could easy spread to any person in the world quite fast. This phenomenon called small world effects is often referred as "six degrees of separation"<sup>17</sup> (Newman 2000). Nevertheless, the concept of fitness landscapes is correlated to the next CAS feature, namely coevolution.

The performed case study provides a good example of a rugged fitness landscape, since the air- and travel industries are highly turbulent and have been since the September 11<sup>th</sup> attack on the World Trade Center. The effects on the development of a new concept for handling baggage are connected to the changes going on in the industry as a whole. The recession in the industry has also been affected by increased price competition between new market entrants such as Ryan Air, Virgin Air and others, competing with less service but low prices; something firms appreciate when they send their staff around the globe. Differentiating the business with more cost-efficient service might be one approach the more established flight companies could benefit from. However, disregarding the ruggedness of the air industry landscape would be devastating when evaluating new logistics concepts. In other words, metaphors with underlying mechanical or positivistic assumptions will not benefit this type of solution in the search for adaptive and robust logistics approaches.

**Claim 10.** *The environment or context of logistics systems could be characterized as a fitness landscape.*

### 3.2.3.2 Coevolution

The three levels of evolution Kauffman presents, as discussed in the previous chapter, could also be evaluated in a logistics context. On the first level, which could be the

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<sup>17</sup> Several experiments have shown that any two people in the world, chosen randomly, will be separated from each other by the typical length of six connection steps, that is one person knowing someone who knows someone etc.

logistical operations within a firm, the evolutionary processes have to some extent shaped the way e.g. the material handling is done or how much storage is usually the case etc. Because different agents and parts are correlated, they affect each other's behavior, which creates coevolution among the agents belonging to the logistics system. However, since the logistics system is interdependent on other parts of a firm or other firms, this means that coevolution exists on a collective level of description as well. For example, changes in marketing strategy certainly have effects in the logistics activities needed to ensure a product reaches the market at the appropriate time.

The baggage handling case study could here exemplify these coevolutionary effects since it involves several firms which are interdependent. Within these firms there are other types of agents, such as departments and groups down to individuals working together. On each level of description coevolutionary processes occur since the agents adapt and modify their behavior to changes and adaptations at other departments or firms. However, to give an example, I will discuss on a firm sense unclear level of description some implications the baggage handling concept would affect. First of all, the travel agency receiving the customer request for a trip to some destination will, in its efforts to increase the degree of service it offers, adapt to customer requirements in its service packages. At the same time, it has to adapt to the other agents involved, that is the flight companies, the airport services and the delivery firms that pick up the baggage according to the customers' requirements. Based on the agents' capabilities, a coevolutionary process will take place between these agents in the development of the logistics service.

**Claim 11.** *Coevolution occurs constantly in logistics systems and it cannot be avoided.*

### **3.2.4 The future**

#### **3.2.4.1 Time**

The agents in a logistics system all anticipate the future, making them both rational and irrational depending on the perspective through which one chooses to view their

actions. From my case study it transpires that the agents perceive the future in different ways, which influences their actual behavior, their self-perception, and the results that can be expected of a process or activity. This anticipation is apparent, no matter what position they hold in a firm. At top management level logistics activities are being evaluated, and different scenarios and strategies are being elaborated and implemented. The notion that the customer demands of tomorrow needs consideration today, is frequently on the agenda. If one takes a taxi driver as an example of other agents, he/she must anticipate which route is the shortest/fastest to get to the airport on a particular day.

**Claim 12.** *The agents involved in logistics systems anticipate the future in their activities and properties.*

### 3.2.5 Conclusions

The conclusion drawn from viewing logistics systems from a complex adaptive system perspective is that the commensurability between the two is clear. All the 12 claims show that the characteristics of a CAS are akin to what can be observed in logistics systems. This means that the main claim stated: *If the commensurability between logistics systems and complex adaptive systems is high, then research carried out in the logistics discipline would benefit from an emphasis on complexity theory and considerations of the proposed paradigmatic view offered in this thesis, is supported in this conceptualization.*

### 3.3 The Pragmatic Approach - Implications for Researchers and Practitioners

*“For 50 years organization science has focused on “controlling uncertainty.” For the past 10 years complexity science has focused on how to understand it so as to better “go with the flow” and perhaps to channel that flow.” (Lissack 1999, p.120)*

One great challenge for logistics researchers and practitioners to reconsider, in developing the logistics discipline, is what the quotation above emphasizes i.e. to understand uncertainty and complexity and “go with the flow” instead of trying to remove and control uncertainty. This reconsideration has to start in a paradigmatic

discourse, since, as stated previously, the ontological and epistemological assumptions are prerequisites for the methodological and method-related assumptions and choices that are being made. Without compliance with the paradigmatic view proposed in this thesis, the pragmatic approach will not bring anything new to the researchers' or the practitioners' agenda. What is proposed in the pragmatic approach demands considerations as to how the future is treated and why, how emergence and self-organization work in the context that is being studied, whether something is controllable and/or designable or not etc. In other words, the pragmatic approach implies consideration of the 12 claims that were established for logistics systems and which also characterize complex adaptive systems.

The first properties of the proposed platform i.e. the CAS feature covering internal properties, are of central importance in order to grasp fully the complexity of a studied system and to understand where it is derived from. The proposed pragmatic approach means taking into consideration the smallest elements of, and agents relevant to, the study being conducted. The proposed approach begins by ensuring that the agents are identified and considered in the context of the phenomenon studied. Further, the agents' dimensionality or degrees of freedom need to be taken into consideration, which means that heterogeneity as well as similarities among the agents i.e. schemata and rules are put in focus in an, for the purpose and context, appropriate manner. Interdependencies among the agents are also of great importance, as is connectivity factors which both link local agents to the global outcomes of their activities.

From this internal approach the mindset of the researcher or practitioner is of great importance in the event of what such an approach might reveal about the problem being studied. In order to capture emergent phenomena and identify self-organization on different levels of description, we need what Richardson, Cilliers, and Lissack (2001) address, a perception of the context as being "gray"; that is not considering the context as something which is static or stable, nor as something totally disoriented and uncontrollable. The metaphorical description of a fitness landscape where coevolution and continuous changes caused by the actions performed by agents inside



## The Pragmatic Approach

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and outside the perceived system under study, could be beneficial in the research process. This is the case since too many reductions of various factors could result in “far-from-reality” based solutions. Reality is here referred to epistemologically as being constructed of different perceived meanings, assumptions, and mental pictures, where the features of CAS are considered and where the future is anticipated as being a paradox of predictability and unpredictability.

There are numerous implications for researchers and practitioners and these concern both the epistemological assumptions and the actual methods being used in the logistics research process. By adopting the CAS platform, a bottom-up approach is promoted in order to deal with logistics problems where the local context is considered, and the systems and phenomena are provided by considerations of the smallest elements relevant to the study. In addition to a mindset aligned to the complexity perspective concluded in the last chapter adopting to the pragmatic approach means developing novel methods as well as emphasizing methods which are in line with a bottom-up perspective.

## 4 Research Process

*“In reality, it seems much more likely that people discover the consequences of their actions only after making them, and even then have little idea of what would have happened if they had done something else. Because of this, inertia, heuristics, imitation, and post-rationalization play an enormous role in the behavior of people in the real world.”* (Allen 2000, p.83)

The research process I am presenting in this chapter is to a great degree a retrospect of what I have carried out in the past. In general, I would like to call my research process emergent<sup>18</sup> instead of deliberated. This because I regard my research process as an emergent outcome of interactions between me and other people I have met, but also an outcome of interactions in the conceptual and abstract space between thoughts I have had and the theories I have studied. I would like to describe my research process through four properties which have been of significance to me during my research journey so far. These are:

**Purposefulness.** My research has been purposeful in general terms but not in detail. I decided two years ago to study for a doctoral degree (now I am halfway through) and I also decided on the subject in large, that of the intersection of complexity theory and logistics. However, the theories and topics I have studied have led me from the belief that complexity was most interesting to discuss in a supply network context involving a great number of firms, to my present state where I now see complexity as something even more interesting since it resides in the interactions of even a small group of people and elements.

**Openness.** During the last part of my research process I have been more consciously aware of new influences and events along the way which benefit my research and me.

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<sup>18</sup> The term emergent refers here to the meaning of the word in the context of complexity theory, see chapter two.

For me, this means to go with the flow of knowledge instead of reducing uncertainty by only focusing on the purpose that was set from the beginning. In other words, being flexible and adaptive to changes may benefit the research process and the results more than holding to a purpose and set of theories stated in the beginning of a research process. This act of being open to new influences took me a long time to understand and I am still striving towards increased understanding and experience.

**Postrationalization.** The research process can only be described in retrospect since most of the means towards the goal are created and/or experienced along the journey. This thinking is in line with my interpretation of the quotation from Allen at the beginning of the chapter<sup>19</sup>. What I will present in the next section under the heading; “What have I done?” is foremost perceived and constructed postrationalization and thereby a simplification of my research process. Indeed, it cannot be anything else since I could not know in advance what each and every day would contribute to my research with insights and problems ranging from theoretical endeavors to lack of motivation.

**Shift in mindset.** This has probably been the most challenging endeavor during my research process. Here I refer to a shift in my mindset, meaning everything from a change in daily vocabulary from deterministic words to more indeterministic ones; from seeking cause-and-effect relations to questioning if such exists in most situations; from me believing in equilibrium states to continual changes of both behavior and structure in society. This shift in mindset is probably the major barrier to studying complexity theory since it takes time, since people will raise objections to new insights gained, and since conceptually it is a great challenge. Nonetheless, the conceptual challenge is something I hope will never diminish.

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<sup>19</sup> See previous page

## 4.1 What have I done?

Figure 4.1 illustrates what I have done in research input and output terms from the day I started until the time I was awarded my licentiate degree.

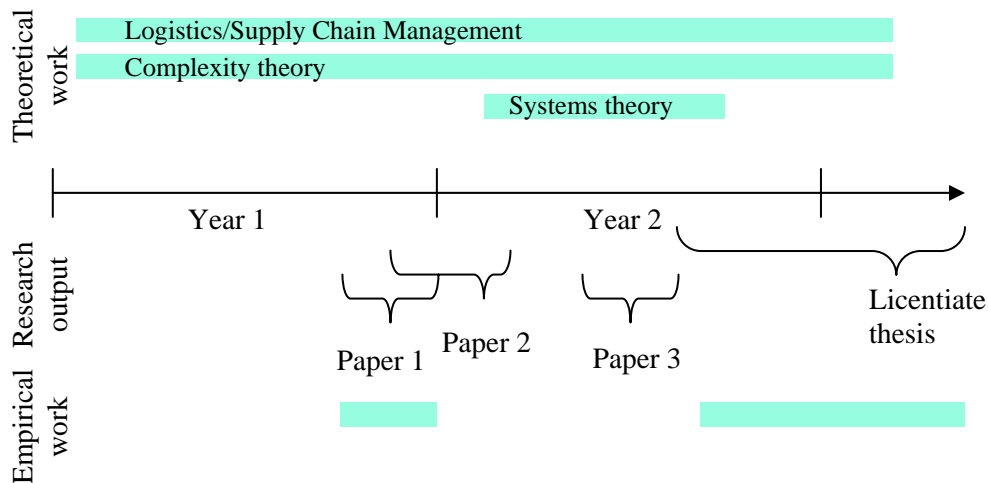


Figure 4.1. My research process.

### 4.1.1 Theoretical Work

If we begin with the theoretical work carried out; an opening, discovery-oriented literature study focusing on mainly logistics, supply chain management and complexity theory was conducted during my first three months. Several branches of complexity theory as well as the origins of complexity theory were studied. These covered areas such as neural networks, mathematics (continuous and discrete), nonlinear dynamics, chaos theory, Marcov processes, statistics, and game theory. These theoretical areas share the same characteristic of being relatively quantitative in their methods, and I regarded this as a drawback, since the chances of obtaining a comprehensive picture of a logistics phenomenon were heavily reduced. However, what motivated me were the conceptually challenging thoughts that complexity writers offered in each and every book I read. This meant that after some time I began to focus on the qualitative, metatheoretical ideas and concepts that were presented and discussed in the complexity theory literature.

On the logistics/SCM track, I became more and more fascinated by supply networks, since recent research into strategic management and supply chain management tends to indicate that much of the competition of tomorrow will not be between firms; it will be between strategic supply networks. (Bovet & Martha 2001; Christopher & Towill 2000; Copacino & Byrnes 2001; Lambert, Cooper, & Pagh 1998) With the insights I had gained from complexity theory, I questioned the use of the term and concept supply chain since what was quite apparent was that the firms, that is suppliers, manufacturers, raw-material producers, retailers, distributors etc., were not positioned in rows like the links in a chain. Instead, what could be observed was that suppliers were spread in network constellation, which continually changed or reconstructed in new owner constellations or with new supplier agreements. However, as my learning and curiosity increased, I started to focus on the foundations of the logistics discipline. The basic premise for this approach was my belief that whether I was studying a simple logistics system or a whole supply network, the underlying assumptions I make would influence the results I might obtain, as well as the methods I would use. This insight became clear to me when I began understanding the impact the science of complexity would have on the logistics discipline.

#### **4.1.2 Empirical Work**

During my first year I conducted a minor case study concerning outsourcing situations for my first paper. The framework for case studies described below (see under heading Case study) was used in order for me to explore different outsourcing situations.

My second case study, which has focused on the baggage handling in the air traveling industry, has been of an exploratory character. The logistics system has been treated as a complex adaptive system and the case shows the indications and the applicability of all the proposed CAS features proposed in this thesis. The purpose of the case study is twofold. Firstly, to act as a case study designated to confirm, exemplify, and explain the features of a CAS, and secondly, to propose the logistical implications of

a new service-oriented approach for established airlines to differentiate themselves from emerging, low-fare airlines.

### **4.1.3 Research Output**

I have produced three papers and the chapters found in this thesis. I will briefly describe each of them below. The papers are to be found as appendices at the end of the thesis.

#### **4.1.3.1 Paper one**

*Interface Complexity and Relative Power in an Outsourcing Context* was my first published paper and we used a central concept in complexity theory, namely interdependence, as a theoretical foundation to evaluate appropriateness of three outsourcing situations.

**Paper one – Abstract:** During the past years outsourcing has evolved into a natural part of companies' strategy to adapt to an increasingly demanding business environment. The decisions are often made for two central reasons; either to focus on core competence or to achieve cost reductions. Outsourcing has brought companies both positive and negative effects through the two reasons mentioned, but there is a need for a more balanced view of the concept of outsourcing. With the use of complexity theory which focuses on interdependence of parts in a system, two cases are analyzed together with a case from literature. The interdependence is divided up into two relevant factors, relative power and interface complexity, which describe the relationship between two companies in an outsourcing situation. A model is proposed, showing how the cases relate to the factors of relative power and interface complexity, revealing if an outsourcing decision is suitable in a certain situation or if caution is to be taken before the decision is made.

#### **4.1.3.2 Paper two**

*A System's Approach for Evaluating Environmental Effects of Transportation;* was my second published paper. It addresses the need for environmental evaluations that include a holistic picture of transportations. This was necessary since several

evaluations only cover point A to point B relations as separate units and then additively sum up the total impact of several interdependent flows.

**Paper two – Abstract:** This paper aims to initiate a new approach in the process of evaluating the environmental impact of logistics in the transportation of goods. Complexity theory and nonlinear dynamics are used in order to find correlations and other effects that are lost in an analytical approach. The research behind this paper is based on a licentiate thesis in which a model for estimating the environmental impact of transportation has been developed. The model is based on an analytical approach where transportation process is broken down into parts and at the end summarized to make a whole. To analyze the parts of a system is, of course, a valid exercise in order to understand how each part works. The next step is then to place the analyzed part in relation to the whole system as well as to the other parts of the system. This step is more difficult to accomplish because of nonlinearity and weak links between the analyzed parts. Using the science of complexity, this second analytical step is examined in order to give researchers, as well as logistics managers, new perspectives on how to estimate the environmental impacts transportation of goods may have. The new approach shows that other perspectives must be evaluated to make it possible to fully understand and judge the environmental impact of the transportation of goods.

#### **4.1.3.3 Paper three**

*Logistics Management from a Complexity Perspective*, challenges the common approach to logistics management. The starting point in the paper is the well-established and often-quoted definition of logistics management provided by the CLM<sup>20</sup>. We conclude in the paper that based on the insights gained from the science of complexity a balanced view of logistics management is called for.

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<sup>20</sup> Council of Logistics Management with the definition of logistics management: “*The process of planning, implementing and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the*

**Paper three – Abstract:** The aim of this paper is to discuss the implications a complexity perspective may have on the management of logistics. The CLM definition of logistics management is used as a base to address the implications a complexity perspective has on the logistics discipline. A framework is developed to assess the logistics complexity based on significant properties (structure, dynamics and adaptation) on three levels of resolution (individual/parts, the firm and the network). The identified emphases on planning and controlling in logistics management are questioned and it is suggested that a change concerning the elements related to the property of adaptation is needed. This means that the processes of planning and controlling have to be balanced against considerations to emergent phenomena and the processes of self-organization taking place in the flow of products and information. One conclusion is that a modified version of the definition of logistics management is called for.

#### **4.1.3.4 The Licentiate Thesis**

My final research output is the chapters in the thesis you are holding in your hands. The aim has been to unify the thoughts presented in the papers and to transform the learning process I have experienced during two years of research into a communicative tool. In other words, the cape acts as a document where I describe and present the insights I have gained so far and I hope that this will encourage other researchers and managers to question their ontological and epistemological beliefs and try out the CAS approach that is proposed in this thesis.

#### **4.2 How have I done it?**

I have used two main methods; one focusing on my main research method, which is my study of literature related to the field, and the other on the empirically oriented case studies that have been conducted. A reason why the thesis has a generally theoretical foundation is that a major drawback in the study of complex systems is the

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*purpose of conforming to customer requirements.” (What’s it all about? CLM book - in Lambert, Stock & Ellram 1998, p.3)*



barrier to understanding what the theory consists of, conceptually as well as mathematically.

#### **4.2.1 Literature Review**

In the research process it is essential, for several reasons, for any researcher to consider the texts written by other researchers. Firstly, to learn what research perspectives and methods are used and what conclusions have been made in the field of investigation. Secondly, it is important to gain insights into terminology, common beliefs, and values in the research field. Thirdly, it is vital to gain knowledge of the current state and trends in the research area under study. Finally, it is important to see how other researchers write in order to gain knowledge about how to target the research market with additional results in the research area. However, in order to learn, and obtain insights from my studies of the chosen literature, a systematic process of how to analyze and synthesize the information gained from the texts has been beneficial. This process has improved my understanding of issues and concepts within the areas of investigation. Moreover, it may also be important for the research community as a whole since it could increase the trustworthiness of what is presented in the thesis.

Influenced by the framework Yin (1994) describes for case study research, I have adopted and developed a similar framework for study of literature in the field I have conducted. My goal has been to provide a systematic approach to the study of literature that I hope will benefit my readers' comprehension and the trustworthiness of my argumentations and results. I have developed a literature review protocol, a literature review database and finally, tools for the study of literature in the field analysis.

##### **4.2.1.1 Literature Review Protocol**

I regard the literature review protocol as a document designated to each area of the literature to be studied. The following areas have been studied and analyzed:

- Logistics – applications
- Logistics – theory and method

- Supply chain management
- Strategic networks and supply networks
- Complexity theory
- Systems theory

The purpose of this protocol is to guide and focus the researcher on each area during the literature review that is to be performed. In the protocol a framework for the following analysis has initially been developed and then continually rearranged during the studies of the literature. What I have primarily used are matrixes where the reading sources have been listed on the horizontal axis and the topics and/or areas of interest on the vertical axis (see table 4.1). This will be discussed in more detail in the literature review analysis section.

	Source 1	Source 2	Source 3
Purpose			
Major conclusions			
Methods used			

Table 4.1 Literature review matrix

#### 4.2.1.2 Literature Review Database

The literature review database is a collection of summaries derived from the vast majority of the literature I have studied. In the reading process the significant information has been scanned<sup>21</sup> and put into the database. By using the original text in the literature it has been possible keep the phrasing of the authors as far as possible, which minimizes possible errors of interpretations when reading a text the first time. It has also been a helpful document for tracing back quotations and statements to their original place in books and articles.

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<sup>21</sup> This scanning has been done by the use of C-Pen™ which is a handheld scanner for scanning texts.

#### **4.2.1.3 Literature Review Analysis**

Based on the framework I developed in the literature review protocol and the information gathered in the literature review database, I have then used several analysis methods; *pattern-matching*, to group arguments and standpoints; *contradictions*, to discover different authors' contradictory statements; *extensions*, to try to find differences from the mass; and *focus*, to highlight on specific results or arguments. This has been done for the purpose of finding new perspectives on the texts and the results.

#### **4.2.2 Case Study**

In order for me to gain insights and impressions from “real-life” contexts, I have used the case study method as research framework. A case study is an inquiry which investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Meredith 1998; Yin 1994). The case study method focuses on the ongoing action, and on processes rather than on "snapshots" of reality, which makes it very appropriate to the complexity perspective since time and change are of great importance when studying complex systems. Eisenhardt (1989) describes the case study as a research strategy which aims at giving the researcher an understanding of the dynamics involved within single settings. It is essential to focus on processes and activities to identify the behavior of a logistics phenomenon being studied. Ellram (1996) argues that, based on their exploratory nature, it is appropriate to use case studies when a new theory is being developed. The appropriateness of using a case study method in the development of new theories motivates the choice of case study as a research method even more since the purpose is to provide new perspectives on, and approaches to, the logistics discipline.

For my case studies I have used techniques that Yin (1994) recommends in the case study design phase. These are 1) create a case study protocol, 2) build a case study database and 3) develop analytical tools for the case study analysis. I will briefly describe these techniques below.

#### 4.2.2.1 Case Study Protocol

The major parts in a case study protocol according to Yin (ibid.) are:

- An introduction, with an overview of the case study project
- Field procedures
- A case study framework with subjects and questions areas
- A guide for the case study report

The case study framework, based on recommendations from Eisenhardt (1989) and Yin (1994), could be seen as a triangulation process within the cases chosen. The framework could be illustrated as a matrix where the following sources of evidence are used: internal documentation, external documentation, interviews, and direct observation (see table 4.2). The sources of evidence are highly complementary, and it is therefore essential to obtain information from as many as possible when carrying out a good case study. This case study framework and the matrix developed is helpful when analyzing the case study because it helps the researcher to become intimately familiar with each case or each part of the case as a stand-alone entity (Eisenhardt, 1989).

	Internal documentation	External documentation	Interviews	Direct observations
Area or topic 1				
Area or topic 2				
Area or topic 3				

Table 4.2. The case study matrix

#### 4.2.2.2 Case Study Database

The case study database is a database where all material collected, in its purest form, is gathered in order to serve as an archive. Purest form refers to e.g. sound files from interviews, original documentation etc. This type of archive could be useful when novel information is gained and one needs to reinterpret some part of the studied object, and when one has to go back for deeper investigations into some issues.

#### **4.2.2.3 Case Study Analysis**

When it comes to the analysis of the data collected during the case studies, a general strategy has been to find irregularities as well as regularities in the studied phenomenon, and to ascertain what major internal and external factors influencing the logistics or organizational processes. The analysis has practically been done in the same way as the literature review process, with a matrix as a framework<sup>21</sup> and with *pattern-matching* as the major approach used in the analysis.

## 5 The Alternative Research Agenda

In chapter one this thesis began with a discussion concerning the development of the logistics discipline based on a more theoretical foundation. The major reasons for adopting for a theoretical development are the perceived stagnation of novel approaches, and the impossibilities of understanding and handling logistical problems based on assumptions aligned to the positivistic paradigm. Consequently, from the author's point of view, this development has to start by taking into consideration the paradigmatic implications i.e. ontological and epistemological assumptions which form the foundation on which the logistics discipline stands. Since it has been identified that positivistic assumptions dominate logistics research, a paradigmatic discourse might be beneficial in order to bring new perspectives, methods, and solutions to logistics-related problems. The goal in this thesis has therefore been to provide an alternative research agenda which places greater emphasis on complexity than that which is usually done in traditional logistics research views and approaches. This is stressed in the purpose in the following way: *“The overall purpose of this licentiate thesis is to propose a paradigmatic view and a pragmatic approach based on the science of complexity that contribute to the further development of the logistics discipline.”*

The fulfillment of this has been accomplished in three papers and the chapters in this thesis. The continuing discussion will be centered on the conclusions and contributions of these four parts.

In the first paper it was concluded that two unifying factors need consideration in order to evaluate potential outsourcing scenarios; namely interface complexity and relative power. Interface complexity is defined as a qualitative function of distances (technical, knowledge, social, cultural, geographic, economic, IT, and legally related) between companies, describing the complexity of the interface between the companies. The second factor, relative power, is defined as a qualitative function of

industry dominance, position in the supply chain, market influence, and relative size in terms of turnover, buying power, and other financial conditions. By considering all these factors and by not putting focus on quantifying them, a high degree of complexity may be taken into consideration, and a more comprehensive picture of the outsourcing situation can consequently be established. While the focus of the paper is on outsourcing situations, the transferability to logistics-related problems is great. In the process of studying and understanding logistics phenomena, where organizations and the agents within them are examined, would certainly benefit from a more inclusive picture. In other words, logistics theories and methods with focus on qualitative aspects, instead of the current emphasis on quantifiable measurements and results, might be beneficial for further development of the logistics discipline. This emphasis on qualitative aspects when examining logistics phenomena is coupled to, and expressed in, the paradigmatic view, which considers far more qualitative aspects than the traditional positivistic view.

In the second paper a complexity perspective was placed on the environmental assessments of transportations. It was concluded in the paper that no research has been found which identifies the environmental effects and consequences associated with transportation systems on a network level. Today the common approach for environmental assessment in transportation focuses on a dyadic level of relations. This lack of research is related to the levels of description available during an analysis of a transportation system or a logistics system, since common approaches in research and industry assess the environmental effects in a linear way, from point A to point B in a system, and then summarize the total effect based on each of these point A to Point B dyadic assessments. The positivistic paradigm underpins this type of assessment method since reductionistic assumptions are evident in the approach and solutions presented. What is proposed in the paper is a change in perspective from the dyadic level to a network level of description and analysis where emergent phenomena i.e. coordination of transportation, synergies among the modes of transportation etc. could be found. This network approach could initiate new types of

environmental assessment methods more aligned to the complex reality one could interpret being out there.

The conclusions of the third paper have been discussed and used in the first chapters of this thesis; consequently, only a short discussion summarizing them will be provided here. Core concepts in the science of complexity such as emergence, self-organization and adaptation was discussed in a logistics context and it was concluded that if the complexity of logistics systems can be modeled and assessed it will give researchers as well as logistics managers a better understanding of logistics, and in the future facilitate a more efficient and effective handling of logistics systems.

When the conclusions and contributions from these papers are synthesized, together they provide the features which are seen to be evident in the CAS platform presented in the second chapter. The core concepts of emergence, self-organization, and adaptation have impacts on several logistics contexts, which in the papers have been emphasized in outsourcing situations, environmental assessments and the analysis of logistics systems in general. Nonetheless, what has not been addressed in the papers is how to approach logistics problems based on the insights from complexity theory i.e. a complexity perspective on logistics. This is the purpose of the chapters in this thesis, that is, to provide an alternative research agenda for the logistics discipline that challenges the dominating positivistic-influenced logistics research agenda of today. The CAS platform for approaching logistics problems is the facilitator for making the complexity perspective useful in a pragmatically oriented context. The applicability of CAS on logistics systems was clear in the analysis<sup>22</sup> and twelve claims based on the features of CAS in the context of logistics were stated. These were:

**Claim 1.** *There are agents with the property of adaptation in logistics systems.*

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**Claim 2.** *The agents in logistics systems are heterogeneous, irrespective of what logistics description level is considered.*

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<sup>22</sup> see pages 43-54



## The Alternative Research Agenda

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**Claim 3.** *Within logistics systems certain schemata and rules are observable in the agents' behavior.*

---

**Claim 4.** *Interdependence among the agents in logistics systems does exist.*

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**Claim 5.** *Connectivity is a central feature in logistics flows, which are the core of logistics systems.*

---

**Claim 6.** *Dimensionality is restrained by a great number of different control mechanisms in the logistics discipline but there is still freedom for each agent to influence and act by him/herself.*

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**Claim 7.** *Emergent phenomena are evident in the logistics context.*

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**Claim 8.** *Self-organization appears in logistics systems since the agents have some dimensionality and the systems are open by nature.*

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**Claim 9.** *The discussion of different levels of description is common in the logistics discipline.*

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**Claim 10.** *The environment or context of logistics systems could be characterized as a fitness landscape.*

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**Claim 11.** *Coevolution occurs constantly in logistics systems and it cannot be avoided.*

---

**Claim 12.** *The agents involved in logistics systems anticipate the future in their activities and properties.*

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Table 5.1. Twelve claims for the applicability of CAS to logistics systems

To provide this alternative research agenda we have to start by challenging the foundations which logistics research stands on today i.e. the metatheoretical foundations. In other words, the positivistic paradigm dominating the logistics discipline needs reconsideration in order for novel approaches and perspectives to be both accepted and considered in further development of the logistics discipline. In this thesis one such perspective based on the science of complexity has been provided and

treated as a paradigmatic view. From this complexity perspective which covers metatheoretical assumptions i.e. a paradigmatic view, a pragmatic approach based on a complex adaptive system platform has been developed as a novel and more comprehensive approach to handling logistics systems and associated problems. The fundamental aspects of the pragmatic approach are a bottom-up perspective, where the smallest elements relevant to a certain logistics problem are considered, the system built up from this and, of course, an alignment with the paradigmatic view based on the science of complexity.

### **5.1 Future Research**

The bottom-up approach that is suggested in this thesis is a seemingly applicable approach to the packaging logistics discipline. The reasons are as follows: I) The common top-down approach used in logistics assumes a holistic view of a defined system. By the alternative use of the bottom-up approach the actual package being transported is the starting point for the investigation – in other words this means taking a perspective from inside the package (Saghir (2002), makes this notion of a view from the package). This way of approaching logistics systems and problems renders packaging logistics as different to the majority of the methodological approaches used in logistics research today. II) With the bottom-up perspective i.e. viewing logistics from inside the package it follows that the system is constructed along the journey the package travels along. By this starting point, the definition of system boundaries becomes an easier term to define since the boundaries are constructed along the movement of the package. III) With the use of agent-based modeling the package could be kept in focus and the emergent outcomes of several packages and other agents identified during the first phase could thereafter be interpreted and analyzed.

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## **Appended papers**

### **Paper 1**

#### **Interface Complexity and Relative Power in an Outsourcing Context**

Presented at the 7<sup>th</sup> International Symposium on Logistics, Melbourne, Australia, July 14-17, 2002. Published in proceeding.

### **Paper 2**

#### **A System's Approach for Evaluating Environmental Effects of Transportation**

Published in the proceedings of the 4<sup>th</sup> International Meeting for Research in Logistics, Lisbon, Portugal, October 14-16, 2002.

### **Paper 3**

#### **Logistics Management from a Complexity Perspective**

Presented at the Managing the Complex IV Conference, Fort Myers, Florida December 7-10, 2002.

Considered for publication in Emergence.



# Paper 1



# Paper 1

## Interface Complexity and Relative Power in an Outsourcing Context

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### **Abstract**

Outsourcing has during the past years evolved into a natural part of companies' strategy to adapt to an increasingly demanding business environment. The decisions are often made for two central reasons, either to focus on core-competence or achieving cost-reductions. Outsourcing has brought companies both positive and negative effects through the two mentioned reasons, but there is a need for a more balanced view on the concept of outsourcing. With the use of complexity theory, focusing on the theory of interdependency of parts in a system, two cases are analyzed along with a case from literature. The interdependency is divided up into two relevant factors, relative power and interface complexity, which describe the relation between two companies in an outsourcing situation. A model is proposed, showing how the cases relate to the factors of relative power and interface complexity, revealing if an outsourcing decision is suitable for a certain situation or if caution is to be taken before the decision is made.



## **Introduction**

As outsourcing has become increasingly used and activities chosen for outsourcing have changed from non-critical to critical for the business processes it has amplified the importance of making the right decision when outsourcing has come into greater focus. In the coming years companies may experience negative effects of outsourcing various activities, causing the outsourcing company to be drained of essential capabilities (Lonsdale 2000). The draining process might cause the outsourced activity to lose its previously strong connection with other internal activities, resulting in poorer, overall business performance (Doig 2001).

Some of the major drivers for outsourcing, recognized in previous research, have focused on core competence, scale economies, production efficiency and strategic flexibility (Quinn, 1999). Although outsourcing is proven to bring about such positive effects on a company it has also been revealed that outsourcing may result in negative effects such as decreased organizational learning, lost control over critical functions, loss of internal unity and loss of company perspectives towards the operating context (Kakabadse, 2000) One of the reasons for this is that decisions to outsource often are based on short-term gains such as cost reductions (Lonsdale, 1999).

While outsourcing activities have been proven to have both positive and negative effects, it has been identified that there is a need for a balanced view of the concept of outsourcing (Lonsdale 2000). By adopting a critical perspective on outsourcing situations we aim to further the debate of outsourcing decisions, in particular when critical activities are targeted. Critical activities are those considered closely linked to the core competencies (Prahalad, 1990).

The concept of outsourcing is discussed through an evaluation of the relationship and the interaction between companies. We argue that the outsourcing decision should not only be based on the strategic issues of core-competence and cost, but that any decision also needs to take into account the interdependence between the activities that are divided, in order for outsourcing companies to be able to succeed in a future

business environment. The interdependence and the relationships between companies have been analysed with the use of complexity theory.

Contrary to the reductionism, the science of complexity represents a scientific approach that does not presume linear cause-and-effect relationships between parts in a system (Gell-Mann 1994). The parts i.e. people, organizations etc., cannot be analysed in isolation because of the non-linear relationships that exist between them (Bar-Yam 1997). The theory has proved its usefulness in several research areas such as physics, biology, economics and business. Its application to supply chain management has hitherto not been particularly explored, despite the applicability complexity theory bears witness to (Lumsden, Hultén, & Waidringer 1998).

### **Interdependence between companies**

A central part of the complexity theory is the interdependence between the parts in a studied system. The interdependence is important because it is in the interactions between the parts that energy and information are transmitted, thus enabling the system to survive and prosper. Bar-Yam (1997) states, “*recognizing the level of interdependence is relevant to various issues pertinent to the functioning and planning of companies*”. By using the concept of interdependence in an outsourcing context it is possible to analyse how the organization as well as the outsourced activity, will be affected once removed from each other. If the outsourced activity is considered valuable in the future i.e. a critical activity, the conditions for each part as well as the connections between the parts must be considered. Put in other words, how the interface is constructed between the parts is fundamental and should be considered essential for further survival and success of the company.

In our analysis the concept of interdependence is divided into an interface part and a dependence part. The interface part will be described as interface complexity and the dependence part will be described as relative power between the companies. Both terms are further discussed later in this paper. The interface complexity and the relative power are used in a theoretical analysis of two case studies (Eisenhardt 1989, Yin 1994), focusing two international companies, one in the telecommunication

industry and the other in the forest industry. These have been chosen to capture outsourcing situations, and together with cases found in the literature, illustrate different situations concerning interface complexity and relative power.

### **Interface complexity**

Interface complexity can be described as the content of the interaction between parts in a system. This interaction, put in a business context, can be represented by e.g. the information, the physical flow of products and the financial flow that takes place between companies. This interaction provides the company with the necessary supply from outside the company that makes it able to perform its part in the supply chain. Interface complexity therefore becomes the complexity of the interaction between the parts in a supply chain, representing a qualitative function of the distances that are present between companies. The distances could, for example, be technical, knowledge, social, cultural, geographic, economic, IT and legally related (Ghemawat 2001; Hammarkvist, Håkansson, & Mattsson 1993). Hence, in this paper interface complexity is defined as a function of these distances, describing the intensity and how many distances constituting the interface between the companies. Interface complexity is also related to the term of transaction cost (Williamson 1979) but also incorporates central distances such as e.g. organizational learning and innovation.

### **Relative power**

The relative power between the parties in an outsourcing situation is an important factor in the decision process. Cool & Henderson (2002) state that if the outsourcing company's industry consists of a relatively low number of actors compared to the supplier's industry, the profitability of the outsourcing company will be higher. When an enlarged amount of critical activities are being outsourced the importance of relative power increases in importance. Alexander & Young (1996) address that placing performance-critical activities in the hands of a supplier can lead to an unhealthy balance of power. As stated, the trend has been that a focus on core competencies is the locus for each and every organization. This was Henry Ford's

policy as well, albeit on a smaller scale, that car production was best achieved if each worker along the line was specialized in his/hers part. Today the trend is similar when companies, at least in theory, specializes in specific parts of the “controlled line”. Bovet & Martha 2001 emphasize this and state, “*outsourced relationships provide efficiency, as each player specializes in its own métier*”. In other words, outsourcing ensures that a new “controlled line” is created, although on a larger scale. The important idea here is the term controlled and especially who is in control or has the most power. In Ford’s case, it was top management that had the relative power over each of the specialized functions. Today, a few cases exist where a major actor, referred to as channel master or network orchestrator has a comparable position and thereby have the power needed to influence the parts that are outsourced. Cisco, Hewlett Packard and Toyota are considered to be in this position (Copacino & Byrnes 2001; Häcki & Lighton 2001). Dyer & Nobeoka (2000) conclude that “*Toyota has the luxury of selecting its “partners” from among the most capable in the world.*” This is a result of Toyota’s dominance over its suppliers and because the suppliers were relatively dependent upon Toyota and normally operated in highly contested markets (Cox 1999b). Hewlett-Packard is another case, according to Cox (1999a), where a dominant actor retains a considerable amount of value within the company even though important parts have been outsourced. Again this is a result based on Hewlett-Packard’s dominance or power in relation to the outsourced party. In this article, we define relative power as a qualitative function of industry dominance, position in the supply chain, market influence, and relative size in terms of turnover, buying power and other financial conditions.

## **Case descriptions**

### **Case: Telecommunication – manufacturing**

This case involves one of the major actors in the telecommunication industry. The Telecom Company decided to outsource its manufacturing to a supplier i.e. the Manufacturing Company (see Figure 1). This was in line with the strategy focusing on core competences such as research and development. Another identified reason for

## Interface Complexity and Relative Power in an Outsourcing Context

this was cost reductions. The Manufacturing Company, which has manufacturing as its core competence, was found to be the most appropriate supplier.

Adopting a relative power perspective on the situation reveals that the power distribution between the Telecom Company and the Manufacturing Company is changing towards greater benefits for the Manufacturing Company. The underlying reasons for this are that while the Telecom Company has had problems, partly because of a market decrease, the Manufacturing Company's operations have grown (see Figure 2). This means that the relative power between the actors is increasing to the supplier's advantage because the customer, the Telecom Company, is becoming the minor player in the relationship between the two of them. The interesting part is that the Manufacturing Company's strategy influences other

actors, i.e. competitors to the Telecom Company, which means that the Manufacturing Company gains competitive advantage and greater influence over the whole industry.

Against the trend of outsourcing, the Manufacturing Company is now in-sourcing other functions. Suppliers are being acquired, a vertical integration strategy, making the Manufacturing Company even more powerful in relation to the Telecom Company and other customers (Figure 3). The change of influence and power

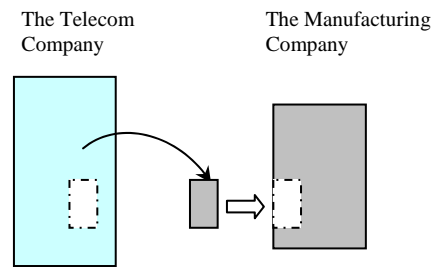


Figure 1: The Telecom Company outsources the manufacturing to the Manufacturing Company.

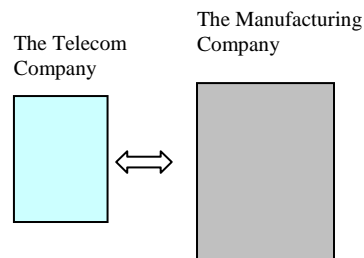


Figure 2: Both companies focusing on their core competences.

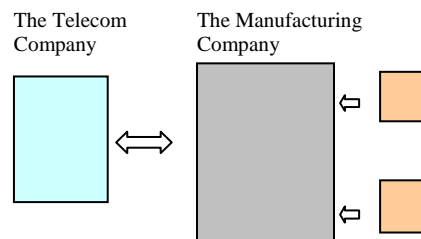


Figure 3: The Manufacturing Company acquires some of its suppliers, the relative power changes.

distribution between the Telecom Company and the Manufacturing Company is a negative effect of outsourcing in this case, at least in the long term.

From an interface complexity perspective the Telecom Company is outsourcing a critical activity i.e. manufacturing, which is directly associated to the value-adding part of the firm. This argument is supported by Ulrich & Eppinger (2000) who state, “*design for manufacturing is one of the most integrative practices involved in product development*”. In the industry of telecommunication, especially in the area of mobile phones, time to volume is a crucial performance measurement because of the brevity of product life cycles. This accentuates the importance of good communication and learning capabilities in the early stages of the product development process. The interface is in this case highly complex because it involves intensive technical and skill-based communication that will be required for each new product to be manufactured.

#### **Case: Forest industry – boiler**

This case concerns an outsourcing situation where a major actor in the forest industry outsourced the investment and the building of a boiler to an energy company. The principal reason for the forest company in making the decision to outsource was to reduce its capital investment. The investment would have to be made whether the boiler was outsourced or not. The cost of the investment could be lowered because due to the fact that the Energy Company had access to capital at a lower rate. Another significant reasons that would ensure the success of the outsourcing decision was that the Energy Company had better bargaining power when it came to fuel for the boiler. Basically, the outsourcing initiative is limited to the investment of the boiler and the provision of fuel for the same. Staff at the Forest Company carry out the maintenance of the boiler.

If we take a relative power perspective on this case, the fact that a contract was signed over an 18 years period makes the agreement fair for both parties, since the terms are set from the beginning, keeping the power balance levelled. As staff from the Forest Company see to the maintenance and the running of the boiler, the Energy Company

will have no chance of exercising any power due to, for example, knowledge on the operational level. Concluding the relative power is levelled between the Forest Company and the Energy Company.

If the perspective of interface complexity is taken on the case, it is revealed that during the development and building phase the numbers responsible for project organization were doubled i.e. one project group was formed in each organization and they overlapped. This caused the administrative costs to rise above normal standards for a project like the one in question. The costs were, however, considered negligible in comparison to the savings that were obtained, and would only be a problem at the beginning of the project. So, except for involvement of the Energy Company at the beginning of the project and in the development and building phase, it is hardly involved at all in the operational running of the boiler. The provision of fuel, which the Energy Company is responsible for, is the only current involvement. This, in turn, is positive for the Forest Company since the Energy Company will be assured a better fuel price than the Forest Company on the market. Since there are clear and simple interaction links between the parties the interface complexity is considered to be low.

## Conclusions

The results from the study indicates that managers in future outsourcing situations must consider both the interface complexity and the relative power in order to be guaranteed a positive outcome of a decision to outsource. Figure 4 illustrates, related to the factors of interface complexity and relative power, our conclusions when considering outsourcing as a strategic tool. If the relative power is high i.e. ranking high on the vertical axis, outsourcing seems to be a beneficial alternative even if the interface complexity is high.

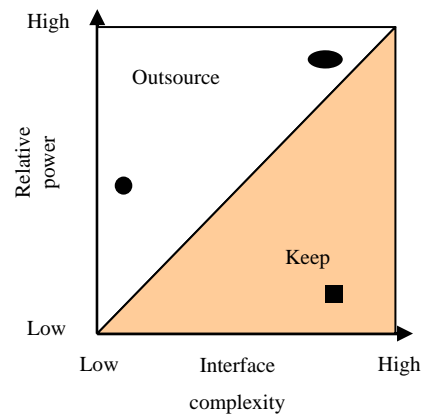


Figure 4: Outsource or keep based on relative power and interface complexity

## A Complex Adaptive Systems Approach on Logistics

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In the telecommunication case, the position in the matrix would be based on a low relative power and a high interface complexity i.e. in the lower right corner (see Figure 4, black square).

The forest industry case shows a situation where the interface complexity is considered low because of a clear interface. Since the activity being outsourced is not regarded as a critical activity and an 18-year-long contract exists the relative power is considered medium (Figure 4, black circle).

These cases can be compared to the discussion of Toyota, where both Toyota's relative power and the interface complexity are considered to be high (Figure 4, black ellipse). This is because of the position and the relative size Toyota has in relation to its suppliers. In other words, outsourcing suits Toyota well since it can influence and control even critical activities with high interface complexity. This means that the higher the interface complexity between the outsourcing company and the supplier becomes, the higher the relative power must be, in order to keep, for instance the draining process of knowledge low and instead guarantee the most beneficial results from the supplier.



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## Paper 2



## Paper 2

# A System's Approach for Evaluating Environmental Effects of Transportation

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### **Abstract:**

This paper aims to initiate a new approach in the process of evaluating logistics environmental impact in the transportation of goods. Complexity theory and non-linear dynamics are used in order to find correlations and other effects that are lost in an analytic approach. The research behind this paper is based on a licentiate thesis in which a model for estimating the environmental impact has been developed. The model is based on an analytic approach where the transportation is broken down into parts and in the end summarized to make a whole. To analyze the parts of a system is, of course, a valid exercise in order to understand how each part works. The next step is then to set the analyzed part in relation to the whole system as well as the other parts of the system. This step is more difficult to accomplish because of the non-linearity and vague links between the analyzed parts. Based on the science of complexity, this second step of analysis is examined in order to give researchers, as well as logistics managers, new perspectives on how to estimate the environmental impacts transportation of products has. The new approach shows that other perspectives must be evaluated to make it possible to fully understand and judge the environmental impact of the transportation of goods.

## **Introduction**

Very commonly, the environmental impact in the transportation of goods is examined in a supply chain, where there is a relationship between two interacting firms, typically a supplier and a manufacturer, or a manufacturer and a customer. Even within firms, the transportation routes are often treated separately and then summed up for the final result. However, in reality, there are more firms as well as more nodes within a firm, interacting and influencing one another than examining this dyad would indicate.

The goal of this paper is to raise questions about the evaluation of environmental impact of goods transportations and suggest methods that capture a holistic picture of the transportations and the links in between them.

## **Supply Networks**

A supply chain is a group of companies working towards servicing the needs of customers (Lambert et al 1998, Bowersox and Closs, 1996). There are several factors that necessitate the increasing importance of developing better relationships between companies interacting and influencing each other, i.e. greater demands from customers and competitors compel companies to focus on ensuring greater value for the customers, in less time. This situation requires the development of supply networks (Christopher, 1998, Cox, 1999, Lambert et al, 1998, Durtsche et al, 1999, Lee, 2000). Durtsche et al (1999) argue that it is ineffective to focus any optimization efforts solely on a company's own logistics operations. If companies are going to act and compete in whole supply networks against other supply networks, there is a great need for new modeling and optimization approaches that encompass the whole and not only the parts, which is the case in several industries today. This is important not only for overall efficiency, but also for environmental reasons. One small change in an organization within a supply network can affect other parts of the network with problems of perhaps greater magnitude than the original problem involved. The majority of the models of today do not take into account global effects of local

actions. Kauffman (1995) states that “*the complex whole may exhibit properties that are not readily explained by understanding the parts*”.

### **Lack of research**

Despite all the statements made by researchers as well as practitioners concerning networks of supply, most of the research that has been carried out deals with only two or three companies in each network (Lamming et al. 2000). Rice and Hoppe (2001) state that there are no proven benefits of coordination and collaboration over more than three tiers in the supply network, and most of the research has only demonstrated advantages in sole-source supplier-customer relationships. Figure 1.1 illustrates the different levels of research carried out in the fields of business, economics and logistics. The figure may also be used to illustrate how research is carried out in the field of environmental matters.

From the bottom, the company level, a great amount of research has been carried out by examining a specific company and all the activities within it. Strategy, organization, finance, marketing and accounting are all theoretical as well as business areas that have been viewed as parts of a company. Life Cycle Inventory analyses are commonly carried out at a company level to evaluate the environmental performance of for example, processes as part of certification processes like ISO 14000.

The next level, the dyadic level, is where some of the logistics research has been focused for a long time. On this level two or three companies and the relationships between them have contributed to the majority of the theory developed in the logistics area of today. It is also on this level that environmental evaluations are carried out when transportations have been evaluated.

The supply network level encompasses whole networks of companies. There you find complex relationships between the actors. This could be seen as an emerging level in the new era of competition. This level of research is interesting to develop because a great amount of the literature available suggests that the competition of tomorrow is



going to be between supply networks (Christopher, 1998, Cox, 1999, Lambert et al., 1998, Durtsche et al., 2000, Lee, 2000).

Finally, at the top, the macro level considerable research has been carried out in the field of economics. Research on the wealth of nations, the global economy and whole industries has been dealt with from many angles and has been done so for a long time. The environmental influence on the future of nations has also been analyzed. This type of research is, however, too general for a company or for a supply network to identify itself with. But a significant contribution has been made to the process of understanding governmental influence on specific industries, and thereby on specific supply networks. The governmental influence on the environmental impact of logistic systems is considerable, as a result of the legislation governing, for example, the amount of goods in vehicles, time restrictions, the availability of certain infrastructures in densely populated areas, or taxes on CO<sub>2</sub> emissions.

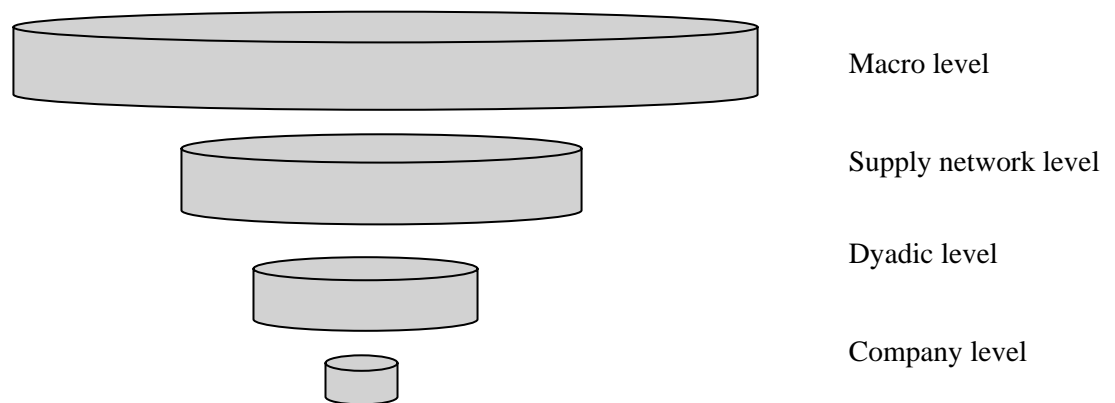


Figure 1. Levels of scope in supply network research

### **Reason for the lack of research**

One could ask why there has not been lot of research carried out on the supply network level. There might be several reasons for this. Firstly, the level is quite new even though companies have worked together for a long time. Secondly, the complication of, and difficulty in, looking at several actors at the same time, without

losing the necessary depth of insight needed. This reason is supported by Beesley (1997). He states that the supply network is complex to handle because of the many interlinked connections between the actors. Thirdly, there could be competing organizations within a supply network that are not willing to share information. Finally, the researcher carrying out the study is sometimes financially supported by one of the actors in the network and then the focus is concentrated on the close relationships with this particular actor.

Nevertheless, there might be great benefits and opportunities to be gained in taking a more holistic approach to the supply network when the aim is to understand environmental influence and the possibility to influence any impact.

### **Complexity theory**

Over the last decade the science of complexity has demonstrated its usefulness in several research areas such as physics, biology, economics and business. The application on logistics has so far not been extensively explored despite the applicability the complexity theory shows (Lumsden et al, 1998). In many descriptions of logistics provided by researchers as well as managers, the trend has been to address a linear approach between relations in the network. The interactions between several actors have been ignored when focus on supply chains has changed from a strategic to an operational level of examination. Still, as in a complex system, a supply chain or a supply network consists of several agents that act in correlation and interdependence to each other (Bar-Yam, 1997). This is a dynamic process where the influence between the agents changes over time (Beinhocker, 1997, Stacey et al., 2000). These agents act according to certain rules which influence their behavior, and thereby the other agents' behavior at the same time. Examples of rules might be where to pick up goods, rules setting out what products to carry in the same vehicle, or costing rules. In the context of a supply network these agents could be, on the largest scale, a network of supply chains and at the finest smallest scale, the people loading the vehicle. Evaluation of supply chains from a complexity perspective provides us with a better understanding about the link between the supply chain and its environment.

### **Complexity science at Southwest Airlines**

This case illustrates how complexity theory can contribute to the evaluation process of logistics systems. The case demonstrates the benefits of taking a holistic perspective on the network instead of focusing solely on each part. Equally important is that the actions of the agents within the system are still examined even if the system is viewed on a larger scale.

Southwest Airlines, which is the fifth largest airline in the US, had problems with its cargo services. It had several bottlenecks in its handling of packages and every time the problem was solved at one airport, problems arose at some other location. The cargo capacity was full at some destinations and high costs arose because cargo had to be locked away overnight at the airports. Despite this, the average fill rate was as low as 7 percent compared to competitors that had a fill rate of 35 percent (Seibel and Thomas, 2001). This led to a situation where Southwest contacted a consultancy firm named Biosgroup, which uses methods and techniques based on the science of complexity to solve problems like this. By taking a network approach, Biosgroup identified several areas which could be improved, for example, the routing of the flights and the material handling at the airports which the following section illustrates.

The ramp agents unloaded and filled the planes at each airport in order to send away the cargo in the right direction as quickly as possible and let someone else handle the packages. If an airplane landed at Las Vegas airport, for example, and a package to Oakland was on that flight, the ramp agents would unload it and try to get it on the next plane to Oakland. Seibel and Thomas (2001) describe this as the ramp agents *“overlooking the fact that the original flight – the one from Albuquerque to Las Vegas, and from Las Vegas to San Francisco – eventually flew to Oakland as well. Therefore, by leaving the cargo on the plane and letting it ride down to San Jose, back to San Francisco, and then on to Oakland, the need to transfer that cargo from one plane to another would be eliminated”*. The ramp agents did not have a holistic network perspective of the routing of the flights or of what effects their own optimization efforts had on the system as a whole.

Bonabeau and Meyer (2001) state that the results from the case show transfer rates reduced by 80 percent at the busiest cargo stations at the same time as the workload for the people moving cargo was decreased by 15 to 20 percent (Seibel and Thomas, 2001). In addition, the number of overnight transfers was reduced, which led to a decreased need for storage facilities and related costs. But the result from the changes made did not only have effects on the cost side. Southwest Airlines estimates today an annual gain of \$10 million because the fill rates on each flight are now higher than ever before (Bonabeau and Meyer, 2001).

The underlying thoughts behind the change process and results described in the case above are some fundamentals of complexity theory. Seibel and Thomas (2001) describe two rules based on complexity theory: 1) First, understand the behavior of the smallest elements, i.e. agents, 2) second, discover the properties of those elements that produce large-scale "emergent" behaviors in the organism.

With these rules and other fundamentals of complexity in mind, the evaluation of environmental impact could be analyzed from a holistic view which emphasizes the connections in the network of transportations. This is not to say that it is a better approach than a strictly analytic evaluation method, but to encompass large-scale effects that result from small-scale behavior, other insights concerning the system studied could be identified. In the following part an analytic model is described in a case for estimating environmental impact of transportation.

### **A model to estimate environmental impact**

The competitive environment in a global society requires that more attention is paid to the environmental consequences of more transportations, at the same time as the logistic efficiency must be constantly improved. The consequence is obviously that logistics managers need to analyze and understand how their activities influence company environmental costs and image (Wu & Dunn, 1995). This is especially important as logistics is well positioned to contribute to lower environmental impact through addressing issues like product design and packaging, as well as energy and resource conservation (Poist, 1989). The logistics manager needs to weigh up options

and select the best alternatives to help the company accomplish the profit goals set. But environmental matters concerns not only better fuel mileage, better fuel or fewer miles driven. It also represents a continuous effort to improve transport modes, vehicles, routes used, as well as the products actually distributed and their packaging.

A method for assessing a selected number of environmental impacts of a transportation is achieved by estimating selected inputs and outputs from a transportation and allocating them to the transported goods (Berglund, 1999). In this way it has been claimed it is possible for each actor using a vehicle to identify its specific environmental impacts. The method is to assess the environmental aspects of a specific transportation process and divide it into two main steps. The first is to estimate the selected input and output from the average means of transportation in a transportation link, and the second is to allocate the input and output to the goods. This requires methods of estimating the inputs and outputs and a method for allocating them to the goods.

The first part of the transportation process accounts for the transportation of goods from the point of loading to the point of unloading. The *average means of transportation* is used to represent the transports in a specific transport link or rail operation. This means of transportation is the most common one used by a specific transportation supplier over a period of time. The average means of transportation is assumed to carry an average load of goods.

In the second part of the transportation process, the concept of a *return transportation* (or back-haul) of the average means of transportation is used to represent the extra movement that can be caused by the first part. The return transportation is viewed as the average means of transportation returning to the place of loading from the place of unloading, regardless of whether or not that is the case. The *return load factor* ( $r$ ) describes the relative share of goods being transported back from the region of destination to the region of loading. On the return transportation the average means of transportation is assumed to carry a load of  $r\%$  of a full load of goods. The philosophy is that the transported goods should bear the environmental aspects of the

“empty part” of the return transportation. The environmental aspect of a return transportation ( $E_r$ ) is assumed to be the same as the environmental aspect ( $E_t$ ) of the transportation. The total environmental aspect of a transportation will then be the sum of the aspect of the transport plus the aspect of the empty part of the return transportation, which can be expressed as:  $E_t * (2-r)$ .

The next step is to allocate the total environmental aspect to the goods. The average means of transportation can, however, be carrying goods other than those for which it is desired to determine the environmental aspect. All the goods transported are simply referred to as *goods* and the desired goods are referred to as *specific goods*. In order to allocate the environmental aspect to the specific goods, one needs to determine their share of the total environmental aspect. This share is referred to as the *allocation factor* ( $a$ ) and is measured by the factor limiting the carrying capacity, which can be weight, volume, or a combination of both.

In order to compare the environmental aspect deriving from the transportation of goods in different transportation solutions, it is desirable to specify the environmental aspect per functional unit of transported goods ( $E_{us}$ ). The number of functional units transported by the average means of transport is denoted ( $u_s$ ). The formula expressing the method is presented below.

$$E_{us} = (E_t + E_r \times (1 - r)) \times a \times \frac{1}{u_s} \quad (1)$$

## Discussion

Based on complexity theory, the model for the estimation of environmental impact (described above) could be modified and treated with a bottom-up process. The first step would be to analyze the agents at each node and the routes of transportation. Each node is specific and the rules governing the nodes should be kept in the model when focus changes to cover how each transportation stage and the handling processes between are viewed from a holistic network approach. The results of the Southwest Airline demonstrate the benefits of analyzing the network, and in particular the interactions in the nodes and the impact on the total performance. This

## A System's Approach for Evaluating Environmental Effects of Transportation

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means that an evaluation of the environmental impact would be more appropriate at the network level than at the dyadic level for the following reasons:

- the identification of an average transportation does not facilitate the possibility to understand variations which normally occur in a system.
- the vehicle, in the case of rail and truck transportations, will be loaded at different times, thus demanding extra transportations, movements of vehicles, different handling equipment and storage. The goods may be loaded in different conditions and consequently require different handling procedures causing environmental impact. In boat and air transportations, the vehicle may be loaded at the same time. However, to accomplish this, the goods have been transported using another transportation mode that may have influenced the goods. There may be damaged goods involved necessitating extra care in the loading process and securing operations that have an environmental impact.
- the transport distance may vary if goods are to come from more than one actor.
- the traveling conditions may vary depending on the goods transported. An empty vehicle has different fuel consumption from a half-full one.
- the speed has a great impact on environmental performance. One small example: by reducing the speed of a ship between Sweden and the Netherlands from 20 to 13 knots, emissions are reduced by half and customer demands concerning delivery service are still met, if the planning of the logistics system has been correctly carried out (Widigsson, 1998).
- there is more equipment used in the loading operations when more than one actor is involved, thus causing different degrees of environmental impact.
- there may be more people involved in handling several types of goods, thus requiring more, and varied, supplementary resources.

- the package design and function are constraints when it comes to transportation, and should be considered in the process of maximizing the goods transported. This would also have impacts on environmental impact.

The list may be extended. However, it illustrates that the greater the degree of coordination in a supply chain, often brought about by environmental concerns, the more complex the interaction becomes between actors in the supply network. At the same time it is obvious that it is not possible to encompass all aspects, even when using the dyadic level approach. By searching for or researching the possibility to find rules and then simulating the non-linear relationship between the goods and the transportations and the handling processes between them, it would be possible to understand the impact of different changes.

### **Conclusions**

So far no research has been found that identifies the consequences of a given problem at a network level compared with the dyadic level. However, there is a great need for such research, as the trend is towards increasing coordination of transportations without knowledge of the consequences on a holistic network level is a concern.



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## Paper 3



## Paper 3

# Logistics Management from a Complexity Perspective

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### **Abstract**

The aim of this paper is to discuss the implications a complexity perspective may have on the management of logistics. The CLM definition of logistics management is used as a base to address the implications a complexity perspective has on the logistics discipline. A framework is developed to assess the logistics complexity based on significant properties (structure, dynamics and adaptation) on three levels of resolution (individual/parts, the firm and the network). The identified emphasis of planning and controlling in logistics management are questioned and it is suggested that a change concerning the elements related to the property of adaptation is needed. This means that the process of planning and controlling has to be balanced by considerations to emergent phenomena and the processes of self-organization taking place in the flow of products and information. One conclusion is that a modified version of the definition of logistics management is called for.

**Keywords:** Complexity, Logistics, Management, Dynamics, Adaptation

## Introduction

This paper sets out to discuss complexity in the context of logistics management. The logistics discipline is considered as a complex system given that it involves interdependent actors with a high degree of interactions. The importance of logistics is predicted to increase since the ability to adjust procurement, production, and transportation to customer demands will, together with the management of fast and accurate information flows, become essential in future business environments (Shankar 2001). Logistics management covers the flow of products and information between firms, that is, logistics activities with the fundamental value-adding features of time and place utility (Ballou 1999, Lambert, Stock and Ellram 1998). Lambert, Stock and Ellram (2001, p. 454) refer to a study made of 100 US firms showing that logistics *“typically had responsibility for outbound transportation, intra company transportation, warehousing, inbound transport, materials handling, and inventory control.”*

The difficulty in coordinating the logistics activities within and among firms is expected to increase since the dependence among interacting firms intensifies and thereby also the ability to deliver to and supply each other. Axelrod and Cohen (2000, p.26) expect *“systems to exhibit increasingly complex dynamics when changes occur that intensify interactions among the elements”*. Thus, handling the logistics system in the supply network will create new demands on logistics management, which means that new approaches and methods are needed for managers to understand and deal with logistics processes.

What logistics management is really about is how to handle the difficulties and complications that constitute logistical problems. Christopher (1998, p.54) observes that *“the complexity of the logistics task appears to be increasing exponentially.”* However, the common approach to handling logistics complexity is based on mechanical assumptions, where the problems are broken down into separate parts that are easy to analyze and solve. With insights from the science of complexity the

authors of this paper take another standpoint by questioning the prevailing thoughts about logistics management. The authors' aim in this paper is to discuss the implications a complexity perspective may have on the management of the socio-technical processes that constitute logistics.

## **Logistics management**

Logistics management is defined by the Council of Logistics Management (CLM) as:

*“The process of planning, implementing and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements.”* (What's it all about? CLM book - in Lambert, Stock & Ellram 1998, p.3)

Based on this definition one could say that logistics management covers several areas where managerial responsibility is addressed. Those are in this paper addressed as *the structure of and the flow within the logistics system, the scope of logistics activities,* and finally *the conformation to customer requirements.*

## **The structure of and the flow within the logistics system**

Logistics systems are often described as a network of nodes and links describing an interconnected web. Wandel and Ruijgrok (1995) establish the basic notion of networks and the correlation between the descriptions of the transport industry as a network. The correlation between the infrastructure, the resources that move on the infrastructure and constitute the transportation network are shown in Figure 1.



## Logistics Management from a Complexity Perspective

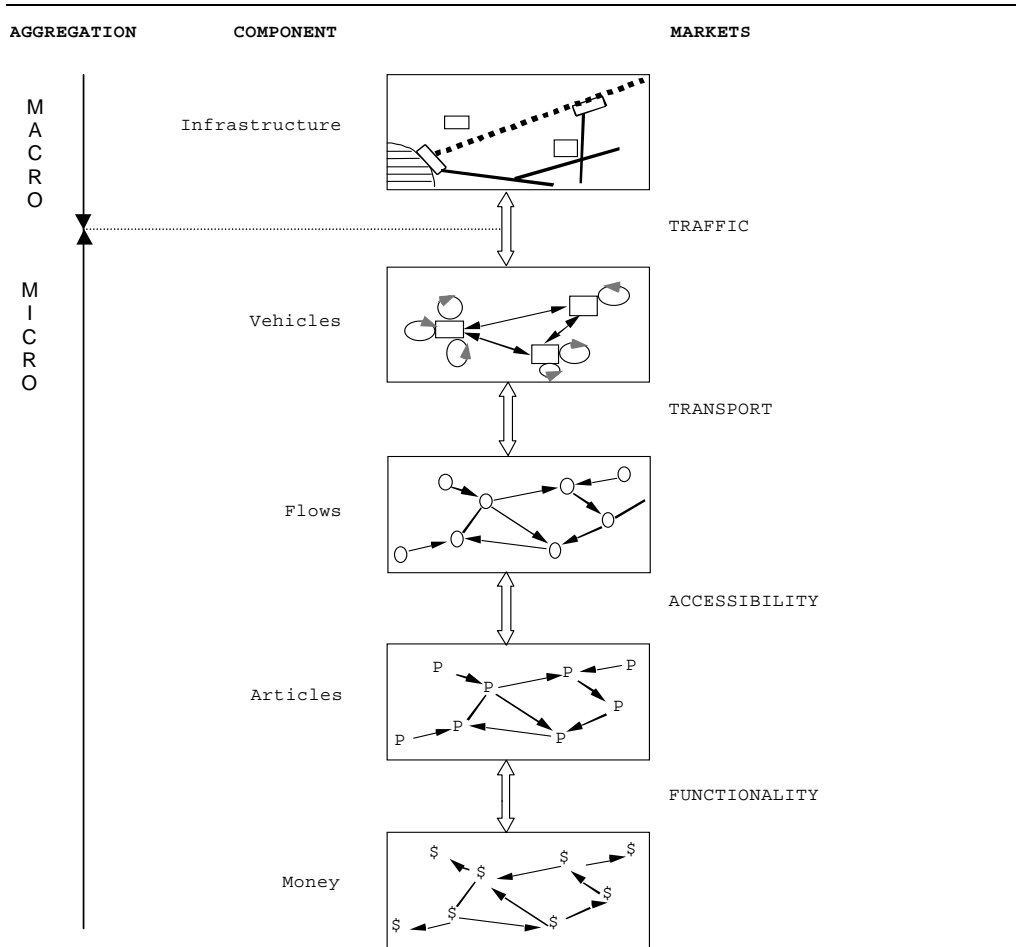


Figure 1 The transport network, resources and infrastructure (Wandel & Ruijgrok, 1995), (derived from Waidringer 1999)

The figure describes the correlation between the aggregation level, from macro to micro, the components of the system and the markets. Traffic is regarded as a market for infrastructure services, e.g. the trade of space and time. Transport is the market for the movement of vehicles on the infrastructure. The accessibility market is the market for flows (or slots) made available by the service providers operating on the transport market. Finally there is a market for functionality that is derived from producer and consumer relations. The consumers buy (using money or an equivalent) articles that give the users a functionality. The model could possibly be expanded to include the

financial market including the macro economic scale but it was not regarded as useful to expand the model that far in this context.

### **The scope of logistics activities**

The scope, in CLM's definition on page 2, *from point of origin to point of consumption* indicates that logistics management covers several firms. This is supported by Bowersox, Closs and Stank (2000) who claim in their conclusion that it has been estimated that only 20 percent of the scope of logistics activities are within the direct control of a firm's logistics function. One reason for this is the evolutionary change of information and physical flows that have reshaped the logistics context from being a question of a number of detailed but not related material flows to complex supply networks. Of major influence are innovations in information technology, which both have fostered a distinct quickening in information processing as well as reduced, for example, the tonnage handled in physical flow. The value-to-weight ratio of a pound of GDP in the US has gone from \$3.64 in 1977 to \$6.52 in 1997, a 79 per cent increase (Meyer, 1999). Consequently, products are easier and hence less costly to move, which has forced industry to reconsider its logistics flows and usage of performance indicators.

Logistics activities and the term supply chain, introduced by Oliver and Webber (1982), have been discussed at different systems levels, as indicated in figure 2. The three stages also describe the basic evolution into more and more integrative solutions that has been noted over the years. For example, the notion of supply chains have been modified, which (Rice & Hoppe 2001) explain by masking the point that supply network is a better term than supply chain when addressing the networks of companies engaged in the supply relationships of today. In the stages below we also incorporate the transformation of logistics from a cost saver inside a specific organization to logistics as a set of activities that supports the strategic intentions of coordinated organizations, as noted by Bowersox and Closs (1996).

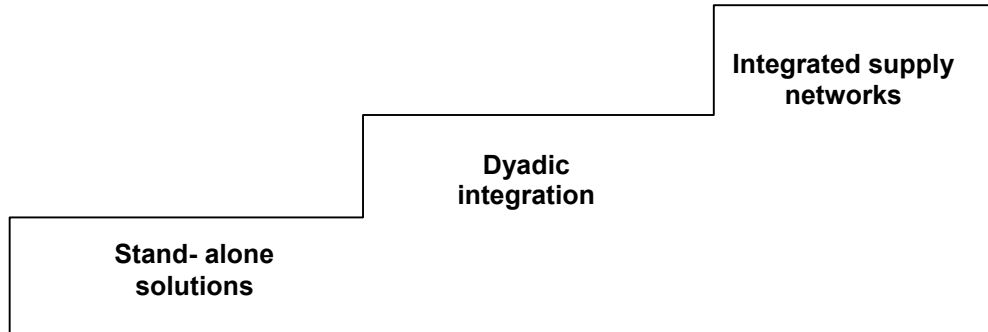


Figure 2. The evolution of logistics solutions (Sjöstedt et al 2001, modified).

In the first stage with stand-alone solutions no actual supply chain can be distinguished and the focus for logistics management is on optimization within the individual firm in order to reach cost savings.

In the second stage with integrated firms in pairs it is possible to talk about an interaction between at least two of the participants in the chain. Cost saving is still an important issue but is supplemented by activities that increase the participants' market shares.

In the last stage, integrated supply networks have been predicted by several researchers to become the dominant organizational form for future competition (Christopher 1998, (Cox 1999b), (Lambert, Cooper, & Pagh 1998), Durtsche *et al*, 2000, (Lee, Padmanabhan, & Whang 1997)). A major reason is greater demands from customers and competitors, which compel firms to focus on delivering greater value to the customers, in less time. In order to satisfy these demands, the ability of suppliers to speed up the innovation process increase. This means that firms are encouraged to cooperate with several other firms and sometimes even transfer several in-house capabilities to suppliers ((Rice & Hoppe 2001), (Bowersox & Closs 1996)). Consequently, the strategic capabilities for a specific firm will then lie in the relationships it has with other firms in its business context. In other words, the network in which firms are involved will be the source of competitive advantage (Gulati, Nohria, & Zaheer 2000), (Kogut 2000).

### The conformation of customer requirements

Satisfying the end-customer's requirements is increasingly becoming the key element for success. Traditionally, the value logistics contributed with was lowering the transportation costs for the firms in the supply chain when they pushed products toward the market. Today, the value is created through adding a service dimension that besides the product features required, gives the customer accessibility to the product based on the customer's demand.

The core function of any logistical system is, in figure 3, simply referred to as management of flows. The figure illustrates how the consumption functions, as part of marketing or other business activities, generate a specification that is transferred through the logistical function to the producer.

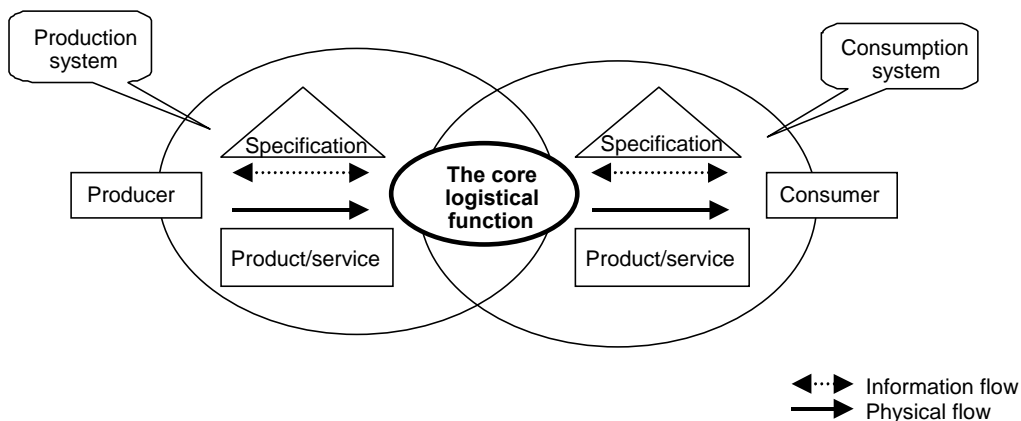


Figure 3. The role of the core logistical function in a Value-Added Industrial System (Sjöstedt et al 2001, modified).

Through the production function the producer materializes the specification into a tangible product or service, which is brought forward to the consumer through the logistical function. The producer has to judge how many resources have to be used in order to meet the specification in a satisfactory way; that is basically a judgment of the market opportunity. The consumer in his or her turn judges how well the product

or service correlates with his or her expectations, a process which in this case basically is a utility evaluation.

## **Complexity in logistics systems**

The notion of logistics systems as being complex is not new, which the following citation, given by Manheim as early as in 1979, shows:

*“Transportation involves the movement of people or goods from one location to another. This requires the expenditure of energy by man, animal or machine., ..., In many cases, especially in industrialized countries, transportation is achieved by quite complex processes in which men and machines interact, within institutions that are often large and complex, to deliver transportation services to customers.”* (Manheim 1979, p.13)

Although Manheim does not define the concept of complexity or discuss how this complexity arises or can be handled, he observes that the logistics system consists of complex processes. However, describing and understanding logistics systems as a class of complex systems is quite recent occurrence.

Even though logistics has been mentioned in articles about complexity before, there are only two articles to the authors' knowledge, that specifically address this issue based on the science of complexity. The first article addresses the complexity as uncertainty involved in supply chains and discusses this from, according to Wilding (1998, p.599), *“three interacting yet independent effects.”* These are deterministic chaos, parallel interactions and demand amplification. These effects cause complexity in the logistical processes based on uncertainty in the supply chain. In the second article, Lumsdén, Hultén and Waidringer (1998) also address the uncertainty of causing complexity, the uncertainty of customer demands and time needed for sub-processes are especially noted. Further, three other aspects are addressed regarding the complexity of logistics systems namely; a large number of system states, heterogeneous system, and distributed decision-making. They conclude that there is a need for *“better models of logistical systems... [that] lead to better predictions of the behavior of real systems”*(p.171). In both articles the complexity, which has arisen in

the logistics systems, is derived from mainly universal and external aspects that can be objectively viewed, and are global phenomena for these systems. However, the impact the parts within these interconnected and interdependent systems have on each other in creating the global phenomena, are not emphasized to a great extent.

Our paper takes the standpoint that complexity in logistics systems appears when technical systems are put in a social context. The technical systems can in themselves be more or less complex, but when the relationships and interaction between technology and man for a certain class of systems is subject to analysis, each system description is too extensive, since in practice it will be impossible for human actors to handle. The most important factors in such a statement are:

- that there exists a infrastructure or network dimension that is characterized by having properties that change slowly. For example the infrastructure is relatively constant since changes take time i.e. when a new road connection is built or a process-machine is placed within a paper mill. This is a technical dimension once structure elements such as the road network or the placement of machines are set.
- the processes in supply networks are changed faster than the network or infrastructure since the processes use this structure. The use of roads or railways can be changed due to many factors such as cost benefits, regulatory changes or new customers on new locations. The processes can both be technical as well as social at the same time.
- that the infrastructure and the processes are influenced by a large number of decision-makers (actors) that are often spread geographically, with different goal functions and different time horizons for their decisions. This is a social dimension.

### **A logistics complexity framework**

In order to discuss logistics complexity a definition proposed by Waidringer (2001) is used:

*Transportation and logistics systems' complexity resides in the nature of the structure, dynamics and adaptation. It is a measure of the possibility of modeling these properties and their interaction in a way that allows of implementation of control mechanisms, forcing the system under study to meet required service, cost and environmental demands. (Waidringer 2001, p.115)*

To address the complexity of logistics activities three properties have been identified within the logistics area that have significant impact for the management of logistics activities. These are *the structure property*, *the dynamics property*, and *the property of adaptation*. The structure property is related to the infrastructure in the context of logistics, and covers physical as well as information and communicational structures. The dynamic property is related to the processes performed on the network i.e. the flow of goods, money and information within the structure and hence the dynamics in these processes. The property of adaptation is related to the organization and the decision-making i.e. the management and control of the structure and the dynamics, in order to realize the processes on the network.

These properties are in this paper put into three different levels of resolution in the context of logistics and the emergent behaviors or patterns in the transition between the levels are then discussed. It is to be noted that these levels are arbitrary and it is regarded as beneficial to adapt these levels to the problem being studied. The levels chosen are: *the individual/parts*, *the firm* and, *the network*.

The individual/parts level is where the smallest relevant elements for a logistics systems description are positioned. These elements are the individuals performing different activities but also artefacts that are being used by the individuals. Together, these elements represent the structure. The actual actions by the individuals are addressed as the dynamics. Finally the adaptation is related to how each individual perceives the effects of his/her own actions as well as actions performed by others which affect both the structure and the dynamics.

On the level of the firm the structure is referred to as the infrastructure within each firm in terms of physical structure and intranet, to informal networks emerging from

connections among the individuals and/or the parts. The structure of the firm and the perceived boundaries provide the cognitive representation for the individuals of what “*constitutes the object of membership, that is, of identity*” (Kogut 2000, p.408). This makes it the internal perspective where the dynamics constitute of the movement of individuals and the flow of objects, information etc. between the structure elements. The distinction between the individual and the firm level is something Lissack (1999, p.111) addresses by firms “*often experience change as an emergent process.*” Still it is the people in the process of sense making that individually and collectively give meaning to the actions (i.e. the adaptation property) that are performed by firms (Lissack 1999).

The network level represents the new organizational form where the structure is referred to the constellation of firms and the infrastructure for both information and physical flow that is being used. The link between the firm structure and the network structure lies in the jointly emergent phenomena embedded in spatially defined networks of labor (Kogut 2000). The dynamics derive from all logistics activities between the firms. Ballou (1997, p.623) states, with relevance to the property of dynamics, that the activities involved on an inter-organizational level are little understood and “*if organizational processes can be developed to deal with logistics matters external to the firm, the firm stands to gain in a way not otherwise possible*”. Concerning the adaptation property of the network, it is considered that both the firm and the supply network are emergent outcomes from interactions of the individuals at the same time as the notion of the firm and the supply network influences the behaviors of the individuals’ actions and perpetual constructions. That is to say that they exist at the same time forming each other.

In order to address the implications a complexity perspective may have on logistics management, the three properties (structure, dynamics and adaptation), and the different levels of resolution are used as a framework.



## **Implications for logistics management**

The identified implications a complexity perspective may have for logistics management will here be discussed based on the framework described above. Since logistics management is connected to other kinds of management there are of course similarities in the type of problems that are being treated. However, logistics is by nature a discipline where a mechanistic approach has been successful since the benefits firms exhibit from logistics are time and place utility of products. Time can easily be divided into time intervals and measured quite easily. The spatial dimension is also rather easy to divide into parts because there is a measurable distance from for example Boston to Chicago. Both these measurements are of a technical character and fit well in the property of structure as well as the property of dynamics since distance is related to structure and time is related to dynamics. With a perspective of reality as being objective it is then quite easy to deal with these properties with a mechanical and summative approach. However, as stated in the framework above, the dynamics, taking place in the structure, is being interpreted by logistics managers that by their actions influence the properties of structure and dynamics. The actions are based on the perpetual construction of reality each individual makes. This, being directly related to the property of adaptation has not been greatly emphasized in logistics management.

## **Planning and Control**

As stated in the CLM definition of logistics management, the focus in logistics is on planning and controlling the activities performed. The easiest way to plan and control is in trying to eliminate the complexity involved. Lambert, Stock and Ellram (2001, p. 453) observe that “*an effective organization must exhibit stability and continuity; it must find a unique offering that it can deliver to the market and stick with it to provide customer value.*” The emphasis on stability and continuity is expressed in the models used which address transportation and logistics, since these are based on equilibrium assumptions (Allen 2000). In other words, the desirable strategy for logistics managers is to reach equilibrium states that are simple enough to handle by

eliminating redundancy and focusing on efficiency and cost reductions. “*Disorder is the price of progress in a dynamic world*” as stated by Quinn (in Coleman 1999, p.38) and this view is also the price for logistics activities.

However, since logistics management covers management of socio-technical processes the dominant approach of planning and control of activities and processes by managers is questioned by the authors. Stacey (2001) describes the view of planning and control as fruitless since the predictability within firms is limited if not impossible and Lissack (1999) argues against this traditional management assumption of control and prediction by stating that with human activity follow emergent outcomes.

The emphasis on planning, and thereby prediction, and control implies a formative and rationalist teleology based on the teleological view Stacey, Griffin and Shaw (2000) describe in their book *Complexity and Management*. A central assumption in logistics management is that the manager has a position outside the system being controlled, which puts him/her in the position of an observer. The manager or the management team has the freedom of choosing the future goals for the logistics system and the capability to design its structure and how and when the flows are determined to take place. This description places logistics management as rationalist teleology since “*the observer has the freedom to choose goals for a system*” and “*even the ability to design it*” (Stacey, Griffin and Shaw 2000, p.72). Added to this is the formative teleology since the manager, in the position of an observer, is able to stand outside the system. Stacey, Griffin and Shaw (2000) especially point out that a formative teleology excludes the interlinked matters of human freedom, the unknown and ethics.

Further, added to the planning and control emphasis, the common approach to handling logistics activities is based on a top-down approach. This means that the actions are planned and decided by the logistics management, which has the ability of viewing the logistics system from “above” i.e. the plan will be based on global logistics phenomena. The planned actions are then properly being distributed to the

right places where each action is performed. However, since “*the complex whole may exhibit properties that are not readily explained by understanding the parts*” ((Kauffman 1995a), the result is that emergent phenomena formed from the bottom-up by local interactions of autonomous individuals and parts, are not being captured. Bonabeau (2002) especially address that emergent phenomena may in several cases be counter intuitive, which make these emergent phenomena impossible for managers to neither plan nor control.

Based on the levels of the resolution described earlier, the individual level is of major importance for logistics management since it is on this level that actions are performed or affected by autonomous individuals. As a result of their actions and the perpetual interpretations of the outcome of other individuals’ actions, global phenomenon emerges. Allen (2000, p.83) points out that as a process of sense making: “*there is a complex and changing relationship between latent and revealed preferences, as individuals experience the system and question their own assumptions and goals*”. Bonabeau (2002) address that it is the individuals within firms (and not processes) that make mistakes and causing errors and he goes as far to point to a paradigm shift from spreadsheet and process-oriented approaches to focus on the individuals.

What is required for logistics management in order to move towards robust network constellations is a shift in mind-set. Park (2000, p.61) address this clearly by stating that “*executives must realize that the old top-down, command-and-control structure is ineffective, and in many cases counterproductive.*” This approach is in line with the new kind of management Tasaka (1999) describes in his article “Twenty-first-century Management and the Complexity Paradigm.” He states that managers should not plan or manage but instead stimulate self-organization. It is through self-organization that the behavior emerges from interactions individuals make with each other (Bonabeau and Meyer 2001).

Consequently, a paradigmatic change from a planning and control approach (top-down) to an emergent and self-organizing approach (bottom-up) would result in

changes in the way logistics activities are being managed. Dent (1999, p.12) describes this as *“how we see things determines much of what we see”*. Therefore is it today impossible to describe what we are expected to see when a complexity perspective has influenced how we see for example the activities related to logistics. However, the transformation of mind-set, from a planning, control, to an emergent and self-organization approach, may have consequences for the definitions used in logistics.

The implications a complexity perspective has on logistics management are here illustrated by a discussion of the CLM definition used in this paper. The first part, *“the process of planning, implementing and controlling”* is what logistics management are doing *“for the purpose of conforming to customer requirements.”* This is by definition related to the property of adaptation since it demands interpretation by people concerning the customer requirements, and especially for logistics management concerning planning and controlling activities needed for customer fulfillment. Since we are living in an increasingly interconnected world there are several factors that might influence the customer requirements, but certainly also the actual flow and storage of products and information. This leaves logistics management with great interpretation consequences since emergent phenomena are unpredictable and the managers are not in the position of an observer or designer standing outside the logistics system. Still, they are supposed to plan and control the flows of products and information in increasingly interconnected supply networks. What is needed to handle this paradox is a more balanced view of planning and control with considerations to emergence and self-organization.

For logistics management to realize the paradox of control and self-organization, a bottom-up perspective on the logistics activities could give novel insights and act as the balanced view. This could act as a complement to the dominant focus on global phenomena and the associated top-down approach related to this. Possible insights might be that logistics managers will learn that the possibility of breaking network level problems down to actions for individuals is difficult. The effects would be interesting and challenging since global patterns identified in complex systems are not possible to be broken down into the behavior of the individuals/parts (Stacey 1996)

## **Conclusions and future research**

This paper has discussed and analyzed the implications of a complexity perspective on logistics and one conclusion is that a modified version of the definition of logistics management is called for. Based on the discussion earlier in this paper would suggest a change concerning the elements related to the property of adaptation. This means that “the process of planning, implementing and, controlling” has to be balanced by considerations to emergent phenomena and the processes of self-organization taking place in the flow and storage of products and information. This will have to be studied further in order to find a better definition, that is more in line with the environment and conditions that logistics management faces in everything from strategic thinking to everyday work.

In this paper only a short assessment of some of the components that give rise to complexity in logistics systems has been made, although these components are considered some of the main factors. In order to assess the full complexity it is necessary to go deeper in the analysis, but the purpose of this paper was mainly to analyze the concept of complexity in the context of logistics management and to show that it is possible and useful to describe and analyze logistics systems in this context. The underlying purpose of this research is that if the complexity of logistics systems complexity can be modeled and assessed it will give researchers as well as logistics managers a better understanding of these systems and in the future facilitate a more efficient and effective handling of logistics systems.

This paper provides another conceptual model to the research area of logistics that hopefully will give an increased understanding of the problems and systems analyzed and that it in this way will be a part of a further development and enhancement of the research into complex logistics systems. Basically the paper has explored if complexity as a concept and metaphor is useful for describing the shortcomings of logistics systems and it has been proved valid in at least one case.

The future research envisaged is twofold, to analyze complexity in logistics systems *per se* and to study different concepts, models and methods that will help us in

understanding and adhering to the requirements of a sustainable society. It is the firm conviction of the authors that there will be an increased demand for more sophisticated solutions to the transport of goods and people which will require more sophisticated approaches, methods and models both to assess these systems properties and to be able to manage and control them in the most efficient way. The concept of complexity is one tool that is possible to use to assess and model logistics systems in order to create a basis for more efficient and effective sustainable logistics solutions.

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## Appendix 1

### Complexity theory ≠ chaos theory

Complexity theory is not just another name for chaos theory. This misinterpretation is something I have encountered several times during my research process and I myself started with that belief only two years ago. Because of this I would like to make the distinction between the two theories since it will benefit the reader and the thesis as a whole.

One major difference between chaos theory and complexity theory is that chaos theory is built on deterministic assumptions and is a purely mathematical fact. According to Strogatz (1997), there is no universally accepted definition of chaos, however, researchers have agreed on three ingredients that a definition should include. This leads to the following definition:

*“Chaos is aperiodic long-term behavior in a deterministic system that exhibits sensitive dependence to initial conditions.”* (ibid. p.66)

The identification of chaos in deterministic systems has contributed to science with novel insights into mathematics and physics, which Baranger (2000 p.8) explains by stating: *“chaos destroys our reductionist dream, the dream that we have absolute power if we only know enough about the details.”*

A significant number of books and articles based on chaos theory were published in management literature at the beginning of the nineties (see for example Levy 1994;Stacey 1993;Wilding 1998a). This use of chaos theory could be regarded as an attempt to shape chaos, as it was defined in physics, to make the strategic landscape fit management. The underlying logic has been that if deterministic systems can behave chaotically, even though initial conditions are measured with high accuracy, then the behavior of a system with less measurable initial conditions is even more difficult to predict i.e. there is no point in long-term planning. Nonetheless, in management literature and research the application of chaos theory to management

## Appendix

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and strategy was the introduction to the applications and discussions about complexity theory which are now emerging.

In complexity theory chaos is regarded as an extreme state, with order at the other extreme.