Interdisciplinary Description of Complex Systems 10(1), 1-15, 2012

A REVIEW OF THE MARITIME CONTAINER SHIPPING INDUSTRY AS A COMPLEX ADAPTIVE SYSTEM*

Simone Caschili[1, 2, **] and Francesca Romana Medda[1]

[1]UCL QASER LAB, University College London
London, United Kingdom

[2]Centre for Advanced Spatial Analysis, University College London
London, United Kingdom

Review *Received:* 7. September 2011. *Accepted:* 23. January 2012.

ABSTRACT

If we consider the worldwide maritime shipping industry as a system, we observe that a large number of independent rational agents such as port authorities, shipping service providers, shipping companies, and commodity producers play a role in achieving predominant positions and in increasing market share. The maritime shipping industry can, from this perspective, be defined as a Complex System composed of relatively independent parts that constantly search, learn and adapt to their environment, while their mutual interactions shape obscure but recognizable patterns. In this work we examine the maritime shipping industry through the Complex Adaptive System (CAS). Although CAS has been applied widely to the study of biological and social systems, its application in maritime shipping is scant. Therefore, our objective in the present paper is to provide a literature review that examines the international maritime industry through the lens of CAS. We also present some of the goals that may be achieved by applying the CAS approach to the container shipping industry in particular. The construction of a tenable ontological framework will give scholars a comprehensive view of the maritime industry and allow them to test the stability and efficiency of the framework to endogenous and exogenous shocks.

KEY WORDS

international trade, maritime container shipping industry, complex adaptive systems

CLASSIFICATION

JEL: F10, B52, O18, R12

PACS: 89.20.Bb, 89.40.Cc, 89.75.-k

*Extended version of the Working paper No. 172, Centre for Advanced Spatial Analysis – University College London

**Corresponding author, η: s.caschili@ucl.ac.uk; +44 (0) 20 3108 3903;
Postal address: 90 Tottenham Court Road, London W1T 4TJ, UK

INTRODUCTION

The significant expansion of global trade, technological advancements and continuous changes in the world's geopolitical scenarios, has typified the development of the contemporary maritime shipping industry. In 1980 the intercontinental shipping freight volume comprised approximately 23 % of the total world volume. At present, many authors estimate that this shipping freight volume ranges between 77 % and 90 % of the transport demand [1-4]. The total number of Twenty-foot Equivalent Units (TEUs) carried worldwide has increased[1] from 28,7 million in 1990 to 148,9 million in 2008; and similarly, average vessel capacity has grown from 1900 TEUs in 1996 to 2400 TEUs in 2006. While in 1996 vessels larger than 5000 TEU constituted only 1 % of the world's fleet, in 2001 vessel capacity had increased to 12,7 % and to 30 % by 2006 [5]. In this context the containerization revolution and technical improvements relative to the size, speed and design of vessels, as well as automation in port operations, have been pivotal to the success of maritime shipping activity [2, 6]. For instance, maritime transport has one of the lowest transport costs per TEU-mile over long distances for large quantities of goods [1]. But as Kaluza et al. [7] observe, another reason must account for maritime shipping success, which they reckon is the growth of transpacific trade that has been fuelled by the globalization process. The container shipping industry has arisen as the leading transportation means for inter-oceanic shipping of manufactured goods, and for this reason we focus our critical overview on the container industry.

In the rapid development of the global maritime system we can observe the presence of various independent rational agents (shipping companies, commodity producers, ports and port authorities, terminal operators, and freight brokers). Mutual interactions among large numbers of independent rational agents determine the growth, and thus the success, of this industrial sector. From this standpoint, our perspective in the present paper is to examine the container shipping industry in particular as a Complex System of relatively independent parts that constantly search, learn and adapt to their environment, while their mutual interactions shape obscure patterns with recognizable regularities that evolve continuously. The science of Complex Adaptive System (CAS) provides a useful framework for the analysis of shipping systems [8-16]; as noted in the literature, CAS refers to a field of study in which its strategic analysis is based on reductionism (bottom-up investigation), and complex adaptive systems are generally composed of a set of rational, self-learning, independent, and interacting agents whose mutual interrelations generate non-linear dynamics and emergent phenomena.

Since the 1980s rational agents in the maritime industry have continuously evolved within their organizations in response to external stimuli such as market competition. In logistics and management structures in particular, new forms of inter-firm organizations have emerged in the shipping industry. Rodrigue et al. [2] explain succinctly how this change has occurred: […] *many of the largest shipping lines have come together by forming strategic alliances with erstwhile competitors. They offer joint services by pooling vessels on the main commercial routes. In this way they are each able to commit fewer ships to a particular service route, and deploy the extra ships on other routes that are maintained outside the alliance. […] The 20 largest carriers controlled 26 % of the world slot capacity in 1980, 42 % in 1992 and about 58 % in 2003. Those carriers have the responsibility to establish and maintain profitable routes in a competitive environment*.

The development of the shipping industry has gone hand-in-hand with changes in port organization. According to a recent study for the European Parliament [17], ports have undergone major transformations in their organizational structures, i.e., they have evolved from the containerization process to what is known as the 'terminalisation era', where ports carry out multi-functional operations through the development of highly specialized terminals.

As the maritime shipping system has evolved, so has the role of port authorities also transformed. Their main duties now involve the optimization of process and infrastructures, logistics performance, the promotion of intermodal transport systems, and increased relations with their hinterlands.

If we assume that international trade can be explained through bottom-up phenomena arising from the interaction among individual agents, it may be possible to understand how new patterns emerge in the global shipping system. In light of the above observations, our objective in this study is to conduct a review with the aim to present a framework for the application of CAS theory to the maritime container shipping industry.

The analysis is organized as follows. In the subsequent sections we review the main features of Complex Adaptive Systems, provide a detailed discussion on CAS methodology, and discuss the opportunity for scholars and practitioners to apply CAS modelling to the maritime shipping industry. We conclude with a research agenda for future studies.

COMPLEXITY SCIENCE AND COMPLEX ADAPTIVE SYSTEMS: KEY CHARACTERISTICS

Various scholars [14, 18, 19] define a Complex System by observing particular features within a given system. These features are: emergent, self-organizing/adaptive, non-linear interactions in evolution. For instance, emergent phenomena are classifiable through the demonstration of their unpredictable behaviours when we account for each part of the system. This concept is exemplified by the famous statement “the whole is greater than the sum of the parts” [19, 20]. Recessions and financial growth are, for example, emergent phenomena of national economies.

The class of CAS is one of the conceptualizations belonging to the framework of Complex Systems. According to Anderson [21], scholars have developed different approaches and theories in their need to better understand Complexity: Mathematical (Turing and Von Neuman), Information Theory, Ergodic theory, Artificial Entities (cellular automata), Large Random Physical systems, Self-Organized Critical systems, Artificial Intelligence, and Wetware. Anderson’s classification places CAS into the Artificial Intelligence approach. What most characterizes this distinctive class of Complex System are the processes of adaptation and evolution. A system is adaptive when its agents “*change their actions as a result of events occurring in the process of interaction*” [22]. Evolution is created through the local interactions among agents. In this sense, adaptation can be seen as a passive action in which the agents absorb information from the surrounding environment (or from previous experience); whereas evolution is generated by the mutual actions among agents. Fig. 1 shows how adaptation and evolution are embedded in different classes of systems.

On the basis of the previous definitions, complex systems must be both adaptive and evolving systems. Unintelligent evolving systems develop through interaction processes but they do not adapt. For example, a crystal is generated by mutual interactions among atoms or molecules that have no intelligence of the process in which they are involved. Furthermore, complicated systems are made by numerous interacting elements that do not adapt or evolve in the system. Complicated artefacts such as a car engine belong to this class. The lower right-hand quadrant in Fig. 1 is empty, as no adaptive system shows static structures. Adaptation and evolution play off each other and by this we mean that the adaptation process includes the concept of evolution but not the reverse.

According to Wallis [23], there is no consensus on CAS unified theory, but Holland [12] nevertheless calls for a unified theory of CAS. Although many authors have developed comprehensive frameworks [8-11, 15], we focus in this work on Holland’s [13] approach to

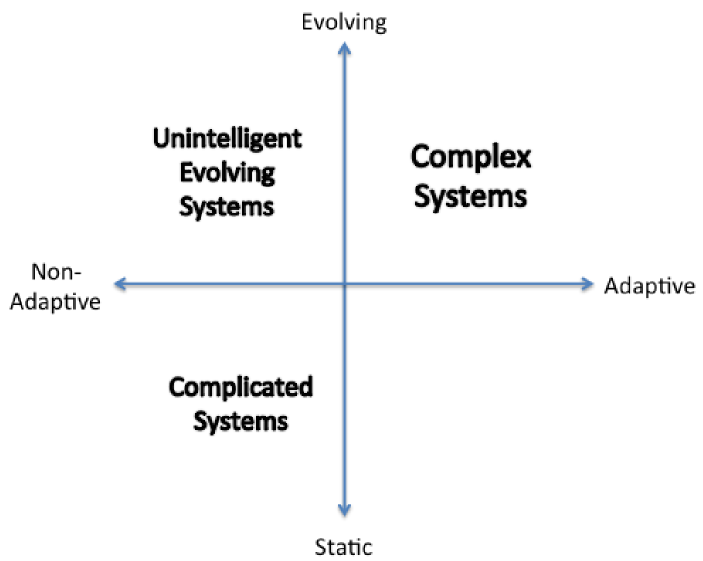

Figure 1. Graph of systems that evolve and adapt.

modelling CAS, which is used widely in much of CAS literature, especially in economic applications. In one of the most robust works towards a unified theory of CAS, Holland [13] suggests four properties and three mechanisms that a CAS must possess. Although Wallis [23] argues that Holland's seven attributes for CAS are not definitive, he nonetheless remarks that "other candidate features can be derived from appropriate combinations of these seven." We present below a summary of the seven basic features and group them into properties and mechanisms.

FOUR PROPERTIES

Aggregation

The concept of aggregation is twofold. The first facet involves how the modeller decides to represent a system. Decisions on which features to leave in and which to ignore are of paramount importance. In this sense elements are aggregated in 'reusable' categories whose combinations help to describe scenes, or to be more precise, "*novel scenes can be decomposed into familiar categories*." The second facet can be ascribed to CAS aggregation properties which relate to the emergence of global behaviors caused by local interactions; in this case agents perform actions similar to other agents rather than adopt independent configurations. Furthermore, aggregation often yields co-operation, in that the same action of a number of agents produces results that cannot be attained by a single agent. We can explain this concept using the analogy of the ant nest. An ant survives and adapts to different conditions when its actions are coordinated with ant group (the nest), but the ant will die if it works by itself. Likewise in a CAS, a new action will survive and induce global effects if it is adopted by a large number of agents.

Non-linearity

Agents interact in a non-linear way so that the global behavior of the system is greater than the sum of its parts.

Flows

Agents interact with one another to create networks that vary over time. The recursive interactions create a *multiplier effect* (interactions between nodes generate outcomes that flow from node to node, creating a chain of changes) and a *recycling effect* (in networks cycles improve local performance and create striking global outcomes).

Diversity

Agent persistence is highly connected to the context provided by other agents so as to define "the niche where the agent outlives." The loss of an agent generates an adaptation in the system with the creation of another agent (similar to the previous) that will occupy the same niche and provide most of the missing interactions. This process creates diversity in the sense that the new specie is similar to the previous one but introduces a new combination of features into the system. The intrinsic nature of a CAS allows the system to carry out progressive adaptations and further interactions, and to create new niches (the outcome of diversity).

THREE MECHANISMS

Tagging

Agents use the tagging mechanism in the aggregation process in order to differentiate among other agents with particular properties; this facilitates a selective interaction among the agents.

Internal models

Internal models are the basic models of a CAS. Each agent has an internal model that filters inputs into patterns and differentiates learning from experience. The internal model changes through agent interactions and the changes bias future actions (agents adapt). Internal models are unique to each CAS and are a basic schema for each system. The internal model takes input and filters it into known patterns. After an occurrence first appears, the agent should be able to anticipate the outcome of the same input if it occurs again. Tacit internal models only tell the system what to do at a current point. Overt internal models are used to explore alternatives or anticipate the future.

Building blocks

With regard to the human ability to recognize and categorize scenes, CAS uses the building block mechanism to generate internal models. The building block mechanism decomposes a situation by evoking basic rules learnt from all possible situations it has already encountered.

An application using all of the seven features allows analysts to define environments where adaptive agents interact and evolve. In the next section we therefore examine two specific studies dedicated to maritime container shipping (The Global Cargo Shipping Network: GCSN) through the lens of Complex Adaptive Systems.

THE GLOBAL MARITIME NETWORK

Only a few studies in the maritime literature focus on the global maritime network, of which the acronym GCSN stands for Global Cargo Ship Network. Scholars have mainly addressed sub-networks of the GCSN, such as Ducruet et al. [24], who have analysed the Asian trade shipping network, McCalla et al. [25] the Caribbean sub-network, Cisic et al. [26] the Mediterranean liner transport system, and Helmick [27] the North Atlantic liner port network. However, two recent articles [5, 7] examine the main characteristics of the complete global network, giving us a view of the macroscopic properties of the global maritime network. In line with our objective here, the aim of both studies is to characterize the global movements of cargo in order to define quantitative analyses on existing structural relations in the rapidly expanding global shipping trade network. But the one main drawback of their studies is their inability to forecast future trends or track changes in the networks.

In Table 1 we highlight the similarities and differences between our two selected studies on the GCSN. Kaluza et al. [7] use the Lloyd's Register Fairplay for year 2007, while Ducruet and Notteboom [5] utilize the dataset from Lloyd's Marine Intelligence Unit for years 1996 (post-Panamax vessels period) and 2006 (introduction of 10 000+ TEU vessels).

By applying different approaches to the network analysis, both studies reach different conclusions in some cases. Ducruet and Notteboom build two different network structures: the first (Graph of Direct Links – GDL) only takes into account the direct links generated by ships mooring at subsequent ports, and the second (Graph of All Linkages – GAL) includes the direct links between ports which are called at by at least one ship. Kaluza et al. [7] differentiate among movements according to type of ship and subsequently construct four networks: all available links, sub-network of container ship, bulk dry carriers, and oil tankers. Despite clear differences between the approaches adopted in the two studies, in order to compare them, we consider the complete network of ship movements from Kaluza et al. [7], and the GAL network of Ducruet and Notteboom [5].

All the networks are dense (average ratio between number of edges and nodes is 37,2). Some network measures indicate a tendency for the GCSN to belong to the class of small world networks[2], given the high values of the Clustering Coefficient[3]. Small world networks are a special class of networks characterized by high connectivity between nodes (or in other words

Table 1. Overview of the main features of the GCSN as proposed Kaluza et al. [7] and Ducruet and Notteboom [5].

	Kaluza et al. network (Year 2007) [7]	GAL (Year 1996) [5]	GAL (Year 2006) [5]
Main features	Asymmetric (59% connections in one direction); structural robustness (densely connected)	Weighted indirect network; small network	Weighted indirect network; small network
# Vessels	Total 11 226; Container ships 3100; Bulk dry carriers 5498; Oil tankers 2628	Container ship 1759	Container ship 3973
Weights	Sum of cargo capacity between port *i* and port *j*	Not specified	Not specified
No. of nodes	951	910	1205
No. of links	36 351	28 510	51 057
Min. shortest path	2,5	2.23	2,21
Clustering coeff.	0,49	0.74	0,73
Average degree; Max. degree	76,5; -	64,1; 437	87,5; 610
$P(k)$	Right skewed but not power law	-0,62	-0,65
$P(w)$	Power law (1,71 ± 0,14)	-	-
Betweenness Centrality	Strong correlation between degree and centrality with some exceptions	Suez and Panama Canals have high centrality (vulnerability of the GCSN)	

words, low remoteness among the nodes). In the maritime setting this property has a significant value; the connections among ports can in fact create clusters of small specialized ports that gravitate around a large port (hub). The large port uses small sub-peripheral ports to sub-contract operations; by so doing, all the ports (hub and peripheral) reach their goals and increase the economic entropy of the system [28].

The expression of the clustering effect, Degree distribution[4] $P(k)$ shows that "most ports have few connections, but there are some ports linked to hundreds of other ports" [7]. However, when the authors examine the degree distribution in detail, they find that the GCSN does not belong to the class of scale free networks. Both studies show low power law exponents or right skewed degree distributions, but if the authors had shown a ranking of the ports over time, the degree distribution analysis would have had a higher significance. This would have informed them if there had ever been a turnover of dominant hubs, which in turn had led to the detection of competitive markets in maritime shipping. Opposite results would have depicted a constrained market.

Kaluza et al. [7] also studied the GCSN as a weighted network where the distribution of weights and Strength[5] displays a power law regime with exponents higher than 1. This finding is in line with the existence of a few routes with high intensity traffic and a few ports that can handle large cargo traffic. The detection of power law regimes is often associated with inequality (i.e. distribution of income and wealth) or vulnerability in economic systems [28, 29]. The correlation between Strength and Degree of each node also fits a power law, implying that the amount of goods handled by each port grows faster than the number of connections with other ports. Hub ports also do not have a high number of connections with other ports, but the connected routes are used by a proportionally higher number of vessels.

Ducruet and Notteboom's work [5] does not provide results of the weighted network analysis over years 1996 and 2006. An analysis of this type would have allowed us to discuss relevant facts about the dynamics of flows in the main interoceanic routes as well as give constructive criticism on the impacts of the introduction of large loading vessels (post-Panamax era) on specific routes.

It is possible to inspect the centrality of ports in a network (i.e. the importance of a node) in addition to other topological measures. In the case of GCSN, both studies use measures of the Betweenness Centrality[6]. Kaluza et al. [7] emphasize a high correlation between Degree k and the Betweenness Centrality, thus validating the observation that hub ports are also central points of the network. Ducruet and Notteboom detect interesting anomalies in the centrality of certain ports. Large North American and Japanese ports are not in the top ranking positions in terms of network centrality despite their traffic volume. The most central ports in the network are the Suez and Panama Canals (as gateway passages), Shanghai (due to the large number of ships "visiting" the port) and ports like Antwerp (due to its high number of connections.)

Although maritime shipping has been experiencing a tremendous period of expansion in the last decade, the underlying network has a robust topological structure which has not changed in recent years. Kaluza et al. [7] observe the differences "in the movement patterns of different ship types." For example, container ships show regular movements between ports, which can be explained by the type of the service they provide; whereas dry carriers and oil tankers tend to move in a less regular manner because they change their routes according to the demand of goods they carry.

Finally, maritime shipping appears to have gained a stronger regional dimension over the years. In 1996 there was a stronger relation between European and Asian basins while in 2006 these connections appear to have weakened. Ducruet and Notteboom [5] explain this as a dual phenomenon. Each basin has reinforced the internal connectivity while the Asian basin is witnessing a strong increase in the volume of goods shipped. The direct consequence is that Asian countries have been splitting their links with European countries. Physical proximity also helps to explain the increase of regional basins as well as the establishment of international commercial agreements such as the NAFTA and MERCOSUR between North and South America [5].

DISCUSSION OF MARITIME SHIPPING USING CAS FRAMEWORK

In the previous section we have discussed two recent studies that consider a static analysis of the global cargo-shipping network. From the previous studies [5, 7] we can conclude that GCSN is a small world network with some power law regimes when it is examined as a weighted network. This evidence indicates that the underlying structure is not dominated by random rules, and that the complex organization emerges from the interaction of lower-level entities.

Self-organization in shipping is identified as a bottom-up process arising from the simultaneous local *non-linear* interactions among agents (i.e. vessels, ports, shipping alliances or nations according to the scale of analysis). This allows us not only to notice that in GCSN our aim is to understand why certain ports are able to play a leading role, but also to estimate the shipping trade trends. Using another example from nature, we know that flocking birds generate patterns based on local information. Each bird learns from other birds and adapts its speed and direction accordingly in order to reach the next spot. Shipping companies compete in the market in the same way in accordance with their own interests. The introduction of innovation makes a company more competitive, new rules are resultantly set in the market which compel other companies to co-evolve in order to be profitable. This adaptive process has been witnessed in maritime shipping at different stages with the introduction of new technologies such as improvements in the fleets (launch of post-Panamax ships) or in port management processes (automation of loading and unloading services).

Based on the work in [5, 7], our next step is to identify a set of CAS features related to shipping systems. We select ten characteristics extracted from a number of works that have proposed applications of CAS modelling [23]. In Table 2 we relate each characteristic to Holland's classification described in Section 2 and to a possible CAS modelling application for shipping systems. In the remainder of this section we discuss how our ten characteristics are constructive elements for a CAS shipping system.

As discussed previously, international shipping involves a large collection of entities (Table 2 – Feature: *Many interacting/interrelated agents*) whose interactions create non-linear trends (Table 2 – Feature: *Non-linear/Unpredictable*). Given these two analytical perspectives, we can examine the local interactions among ships and show how they are assigned to different ports according to price and demand for the goods they carry (Table 2 – Feature: *Goal seeking*). Conversely, according to the modelling proposed in [5, 7], seaports may be considered as agents of a CAS. In this case the most interesting questions revolve around understanding how a shipping system evolves in relation to external shocks (Table 2 – Feature: *Co-evolutionary*). For instance, in cases of sudden undesired events such as terrorist attacks or extreme natural phenomena (earthquakes and hurricanes), the maritime shipping network would *co-evolve* in order to maintain the same level of provided service if a big seaport hub were to disappear or be severely damaged.

If we return to our analogy of natural systems, we can raise some fundamental questions: how would an ecosystem evolve if a species were to disappear? Would an extinct species be replaced by new species and would other species be able to survive without it? Similarly, we

Table 2. Comparison of Complex Adaptive System (CAS) features with shipping.

Feature	Description	Refe-rences	Holland basics	Maritime shipping system
Self-orga-nization	Formation of regularities in patterns of interactions of agents that pursue their own advantage through simple rules.	34-42	Tagging, non-linearity	The GCSN is a small world network with some power law regimes when inspected as a weighted network. This evidence shows that the underlying structure is not dominated by random rules, and that complex organization emerges from the interaction of lower-level entities.
Many interacting, interrelated agents	Large number of locally-interconnected and interacting rational agents that continually pursue their own advantage.	34-38, 43-52,	Flows, tagging	This concept is already embodied in the definition of the maritime shipping system. If we only consider the fleet system and the connections established between ports, we observe approx. 10 000 vessels, 1000 ports and 50 000 connections (see Table 1 for details).
Distributed control	CAS's outcomes emerge from a self-organization process rather than being designed and controlled by a centralized body or externally	12, 14, 43, 51, 52	Flows, internal model	Although there are international trade agreements that unavoidably influence maritime shipping, these pacts can be seen as external forces that increase system entropy and prompt more economic relationships.
Non-linear unpredic-table	Interactions are non-linear and thus intractable from a mathematical point of view.	14, 22, 28, 36-38, 40, 43, 45-49, 46, 53	Non-linearity	The GCSN shows power law fit distributions and not random topological structures, thereby signalling the emergence of non-linear interactions between a system's agents.
Co-evolu-tionary	The environment is influenced by the activities of each agent.	43, 45, 46, 36, 39, 54, 41, 52	Diversity and tagging	i.e. introduction of post Panamax and 10 000+ TEU ships change carriers routing networks and tariffs as well as the volume of transshipped cargo handled at main ports.
Emergence	Interplay between agents shapes an obscure but recogni-zable regularity (e.g. the brain has consci-ousness but single neurons have not)	52, 12, 14, 53	Aggrega-tion, flows, internal model	i.e. emergence of regional clusters of ports.
Goal seeking	Agents try to adapt in order to fulfil	43, 34, 44, 50,	Flows, internal	Dry carriers and oil tankers tend to move in an irregular manner

	goals.	54, 41	model	because they change routes according to demand for the goods they carry.
Nested systems	Each agent can be considered as a system. Each system is part of something bigger, thus each system can be a sub-system of a bigger system.	55, 5]	Diversity and internal model	Port alliances at national or international level are nested clusters of ports. The same port may belong to a cluster of ports at national level and to a cluster of ports at inter-national level, but this category may not necessarily include all the ports to which it belongs within the national cluster.

can apply such questions to the case of maritime shipping in order to forecast future configurations and prevent global breakdowns in national and international markets (Table 2 – Feature: *Self-organization*).

The maritime shipping industry is comprised by several relevant sectors such as international maritime transport, maritime auxiliary services and port services; they have a fairly long history of co-operation since the 1990s with the formation of consortia and alliances. Each co-operation is regulated by a wide range of "*national and international regulations responding to specific issues that have arisen as the international trading system has evolved*" [33]. The outcomes of these collaborations influence the setting of freight rates and shipping company tariffs. In light of the previous remarks, co-operation among agents (shipping companies, port authorities, and so on) should be included in the modelling (Table 2 – Features: *Distributed control* and *Nested Systems*).

In particular, international economic alliances in trade agreements are influential in the definition of trade flows and development. For instance, China's admittance into the WTO has affected the bilateral negotiations between WTO countries and China itself as well as among former members (Table 2 – Feature: *Co-evolutionary* and *Self-organization*), but other examples of international trade agreements show similar impacts on international trade processes (NAFTA among North American countries, MERCOSUR in South America, ASEAN-AFTA among five Asian countries, the Trans-Pacific Strategic Economic Partnership (TPP) in the Asian-Pacific region).

On the basis of the observations discussed above, when we model shipping relationships trade agreement memberships should be included for two reasons: firstly, to understand the actual effects on agents involved in the agreements; and secondly, to understand the effects generated on agents who are not members of a specific trade bloc. In this regard, a CAS application on maritime international trade would help us to better assess the role of alliances in trade, the effects of the establishment of new alliances, and the admission of new members in existing agreements (Table 2 – Feature: *Emergence*).

The aforementioned are some of the questions a CAS application should potentially be able to answer when policy constraints are reckoned with the agents' behaviour modelling (Table 2 – Feature: *Distributed control*). Referring to Holland's classification, the modeller has to set up the internal model of each agent so that it takes into account the distinguishing factors an agent uses to direct its economic choices. For example, national and international port alliances are nested clusters of ports. A single port may belong to a cluster of ports at national level and also belong to a cluster of ports at international level. But not all ports in a national cluster are necessarily part of an international cluster; these structures emerge during the mutual interactions between agents.

CONCLUSION: CHALLENGES, BENEFITS AND FLOWS OF CAS

The global financial and economic crisis of 2008 has made vulnerable the intricate chain of activity which comprises the maritime industry. Rapid growth since 1980 in the volume of freight handled, technical improvements and logistics reorganization has prompted the development of complex interactions among independent agents in the maritime industry (i.e. shipping companies, commodity producers, ports and port authorities, terminal operators, and freight brokers). From this perspective, maritime industry may be considered as a system composed of interacting, intelligent and adapting elements. Under this lens of analysis, Complexity theory and Complex Adaptive Systems (CAS) provide us with an established theory and mathematical toolkit for the study of maritime industry. Opposite from classic top-down approaches whose modeling components are carefully designed and evaluated, the CAS theory proposes bottom-up methods based on the modeling of simple interactions among its components (or agents) that generate complex, robust and flexible phenomena and macro-regularities.
Our aim in the present paper has been to review the maritime literature and demonstrate how CAS theory can be applied in the maritime industry in order to achieve the following objectives:

- to test the stability and efficiency of the maritime container shipping industry to endogenous and exogenous shocks such as global downturns and piracy attacks,
- to understand the spatial structure and organization of the formation of regional clusters of ports, business agglomerations and industrial alliances,
- to understand why certain types of co-operation among shipping firms appear to be more adaptable than others, and to know which factors regulate the stable relationships among them;,
- to provide policy makers with a set of comprehensive tools able to address issues of growth, distribution and welfare connected to global trade trends.

For instance, a crucial problem upon which a CAS approach may be able to shed some light is the assessment of the resilience of the maritime industry system to shocks. In recent years, in conjunction with the rapid growth in shipping, piracy attacks have increasingly been carried out on cargo vessels. Their goal has been to kidnap personnel on board and force companies to pay high ransoms for their employees' lives. This activity is presently impacting on the logistics management of carriers. In fact, among other preventative measures applied by management, carriers are changing their routes in order to protect their vessels from attack. Especially in the proximity of the Horn of Africa, where most attacks have taken place in the last few years, we have registered an increase in changes of routes, where vessels have tended to navigate as far away as possible from coastlines. Thus, in the case of piracy we are observing an adaptation of the maritime system to external factors that are also driving economic and political changes in areas affected by these phenomena.

In addition to the problem of piracy, the recent financial and economic international crisis has caused a breakdown in the container industry. In response to this external shock, co-operation among container companies has increased. In order to stay profitable in the present unstable market, carriers have gradually adopted co-operative schemes in a number of container services [59], thereby creating new options for carriers that can adapt their financial strategies in order to share the level of investment as well as the financial risk.

We can conclude by observing that the CAS approach, beyond other econometric approaches, may be more suitable in the aim to reproduce dynamic and rapid changes of markets [13].

The challenge now is to set up an integrated multidisciplinary approach in practice. Scholars have already thrown down the gauntlet to the scientific community of a multidisciplinary approach using the CAS paradigm [13, 56] alas, not yet in maritime shipping.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the Engineering and Physical Sciences Research Council (EPSRC) under the grant ENFOLD-ing: Explaining, Modelling and Forecasting Global Dynamics, reference EP/H02185X/1.

REMARKS

[1]Source: World Container Traffic – Drewry Annual Reports; End Year Fleet Size – CI Market Analysis: Container Leasing Market 2010.
[2]For an extensive review of complex networks, see [30-32]
[3]A measure of the tendency for nodes to cluster together.
[4]In Network Theory degree k represents the number of connections of every node.
[5]In the case of ship networks, Strength represents the sum of goods passing through a port in one year: the sum of the links' weights that converge on a node.
[6]The Betweenness Centrality of a node is the number of topologically shortest paths that pass through that node.

REFERENCES

[1] Rodrigue, J.P.; Comtois, C. and Slack, B.: *The Geography of Transport Systems*. Routledge, London, 2006,
[2] Rodrigue, J.P.; Comtois, C. and Slack, B.: *The Geography of Transport Systems*. 2nd edition. Routledge, New York, 2009,
[3] Glen, D. and Marlow, P.: *Maritime Statistics: A New Forum for Practitioners*. Maritime Policy & Management **36**(2), 185-195, 2009,
[4] Barthelemi, M.: *Spatial Networks*. Physics Reports **499**, 1-101, 2011,
[5] Ducruet, C. and Notteboom, M.: *The Worldwide Maritime Network of Container Shipping: Spatial Structure and Regional Dynamics*. GaWC Research Bulletin 364, 2010,
[6] Notteboom, T.: *Container Shipping and Ports: An Overview*. Review of Network Economics **3**(2), 86-106, 2004.
[7] Kaluza, P.; Kolzsch, A.; Gastner, M.T. and Blasius, B.: *The Complex Network of Global Cargo Ship Movements*. Journal of the Royal Society Interface **7**(48), 1093-1103, 2010,
[8] Arthur, W.B.: *Introduction: Process and Emergence in the Economy*. In: Arthur, W.B.; Durlauf, S. and Lane, D.A., eds.: The Economy as an Evolving Complex System II. Reading, Boston, pp. 1-4, 1997,
[9] Dooley, K.: *Complex Adaptive Systems: A Nominal Definition*. The Chaos Network **8**(1), 2-3, 1996,
[10] Gell-Mann, M.: *Complex Adaptive Systems*. In: Cowan, G.A.; Pines, D. and Meltzer D., eds: Complexity: metaphors, models, and reality. Addison-Wesley, pp. 17-45, 1994,
[11] Gell-Mann, M.: *The Quark and the Jaguar: Adventures in the Simple and the Complex*. Owl Books, New York, 1995,
[12] Holland, J.H.: *Adaptation in Natural and Artificial Systems*. The MIT Press, Cambridge, 1992,

[13] Holland, J.H.: *Hidden Order: How Adaptation Builds Complexity*.
Addison Wesley Publishing Company, 1995,

[14] Holland, J.H.: *Emergence: From Chaos to Order*.
Addison-Wesley, Redwood City, 1998,

[15] Levin, S.A.: *Ecosystems and the Biosphere as Complex Adaptive Systems Ecosystems*.
Biomedical and Life Sciences and Earth and Environmental Science **1**, 431-436, 1998,

[16] Levin, S.A.: *Complex Adaptive Systems: Exploring the Known, the Unknown and the Unknowable*.
Bulletin (New Series) of the American Mathematical Society **40**(1), 3-19, 2003.

[17] European Parliament Directorate-General for Internal Policies: *The Involving Role of EU Seaports in Global Maritime Logistics – Capacities, Challenges and Strategies*.
PE 419.121, Policy Department B: Structural and Cohesion Policies, 2009,

[18] Corning, P.A.: *The Re-emergence of "Emergence": A Venerable Concept in Search of a Theory*.
Complexity **7**(6), 18-30, 2002,

[19] Markose, S.M.: *Computability and Evolutionary Complexity: Markets as Complex Adaptive Systems (CAS)*.
The Economic Journal **115**(504) F159-F192, 2005,

[20] Buchanan, M.: *Ubiquity: Why Catastrophes Happen*.
Weidenfeld and Nicolson, London, 2002,

[21] Anderson, P.W.: *The Eightfold Way to the Theory of Complexity: A Prologue*.
In: Cowan, G.A.; Pines, D. and Meltzer, D., eds: Complexity: metaphors, models, and reality. Addison-Wesley, pp. 7-16, 1994,

[22] Kochugovindan, S. and Vriend, N.J.: *Is the Study of Complex Adaptive Systems Going to Solve the Mystery of Adam Smith's Invisible Hand*?
The Independent Review **3**(1), 53-66, 1998,

[23] Wallis, S.E.: *Emerging Order in CAS Theory: Mapping Some Perspectives*.
Kybernetes **37**(7), 1016-1029, 2008,

[24] Ducruet, C.; Lee, S.W. and Aky, N.G.: *Centrality and Vulnerability in Liner Shipping Networks: Revisiting the Northeast Asian Port Hierarchy*.
Maritime Policy and Management **37**(1), 17-36, 2010,

[25] McCalla, R.; Slack, B. and Comtois, C.: *The Caribbean Basin: Adjusting to Global Trends in Containerization*.
Maritime Policy and Management **32**(3), 245-261, 2005,

[26] Cisic, D.; Komadina, P. and Hlaca, B.: *Network Analysis Applied to Mediterranean Liner Transport System*.
Proceedings of the International Association of Maritime Economists Conference. Athens, 2007,

[27] Helmick, J.S.: *Concentration and Connectivity in the North Atlantic Liner Port Network, 1970-1990*.
University of Miami, Miami, 1994,

[28] Foster, J.: *From Simplistic to Complex Systems in Economics*.
Cambridge Journal of Economics **29**(6), 873-892, 2005,

[29] Pareto, V.: *Cours D'économie Politique Professé a l'Université de Lausanne*. Vol. I.
Paris, 1897,

[30] Watts, D.J. and Strogatz, S.H.: *Collective Dynamics of 'Small-World' Networks*.
Nature **393**, 409-410, 1998,

[31] Albert, R. and Barabási, A.L.: *Statistical Mechanics of Complex Networks*.
Reviews of Modern Physics **74**, 47-97, 2002,

[32] Newman, M.E.J.: *The Structure and Function of Complex Networks*.
SIAM Review **45**(2), 167-256, 2003,

[33] Directorate for Science, Technology and Industry - Division of Transport: *Regulatory Issues in International Maritime Transport*.
Organization for Economic Co-operation and Development (OECD), 2003, http://www.oecd.org/dataoecd/0/63/2065436.pdf,
[34] Brown, S.L. and Eisenhardt, K.M.: *Competing on the Edge: Strategy as Structured Chaos*.
Boston, Harvard Business School Press, 1998,
[35] Harder, J.; Robertson, P.J. and Woodward, H.: *The Spirit of the New Workplace: Breathing Life into Organizations*.
Organization Development Journal **22**(2), 79-103, 2004,
[36] Bergmann Lichtenstein, B.M: *Emergence as a Process of Self-organizing: New Assumptions and Insights from the Study of Nonlinear Dynamic Systems*.
Journal of Organizational Change Management **13**(6), 526-544, 2000,
[37] McDaniel, R.R.; Jordan, M. and Fleeman, B.: *Surprise, Surprise, Surprise! A Complexity Science View of the Unexpected*.
Health Care Management Review **28**, 266-278, 2003,
[38] McKelvey, B.: *Toward an 0th Law of Thermodynamics: Order Creation Complexity Dynamics from Physics and Biology to Bioeconomics*.
Journal of Bioeconomics **6**, 65-96, 2004,
[39] Pascale, R.T.: *Surfing the Edge of Chaos*.
Sloan Management Review **40**(3), 83-95, 1999,
[40] Tower, D.: *Creating the Complex Adaptive Organization: a Primer on Complex Adaptive Systems*.
OD Practitioner **34**(3), 2002,
[41] Zimmerman, B.; Lindberg, C. and Plsek, P.E.: *Edgeware: Insights from Complexity Science for Health Care Leaders*.
Veterans Health Administration, Irving, 1998,
[42] Axelrod, R. and Cohen, M.D.: *Harnessing Complexity: Organizational Implications of a Scientific Frontier*.
Simon & Schuster, New York, 2000,
[43] Chiva-Gomez, R.: *The Facilitating Factors for Organisational Learning: Bringing Ideas from Complex Adaptive Systems*.
Knowledge and Process Management **10**(2), 99-114, 2003,
[44] Daneke, G.A.: *Systemic choices: Nonlinear Dynamics and Practical Management*.
University of Michigan Press, Ann Arbor, 1999,
[45] Dent, E.B.: *The Complexity Science Organizational Development Practitioner*.
Organization Development Journal **21**(2), 82-92, 2003,
[46] Hunt, J.G. and Ropo, A.: *Longitudinal Organizational Research and the Third Scientific Discipline*.
The Leadership Quarterly **28**(3), 315-340, 2003,
[47] McGrath, J.E.: *Small Group Research, that Once and Future Field: An Interpretation of the Past with an Eye to the Future*.
Group Dynamic: Theory, Research and Practice **1**(1), 7-27, 1997,
[48] Moss, M.: *Sense Making, Complexity and Organisational Knowledge*.
Knowledge and Process Management **8**(4), 217-232, 2001,
[49] Olson, E. and Eoyang, G.: *Facilitating Organizational Change: Lessons from Complexity Science*.
Jossey-Bass, San Francisco, 2001,
[50] Kurtz, C.F. and Snowden, D.J.: *The New Dynamics of Strategy: Sense-Making in a Complex and Complicated World*.
IBM Systems Journal **42**, 462-483, 2003,

[51] Keshavarz, N.; Nutbeam, D.; Rowling, L. and Khavarpour, F.: *Schools as Social Complex Adaptive Systems: A New Way to Understand the Challenges of Introducing the Health Promoting Schools Concept*.
Social Science & Medicine **70**(10), 1467-1474, 2010,
[52] Seel, R.: *Complexity and Culture: New Perspectives on Organisational Change*.
Organisations & People **7**(2), 2-9, 2000,
[53] Stacey, R.: *Complexity and Creativity in Organizations*.
Berrett- Koehler, San Francisco, 1996,
[54] Funtowitcz, S.O. and Ravetz, J.R.: *Emergent Complex Systems*.
Futures **26**(6), 568-582, 1994,
[55] Tesfatsion, L.: *Agent-based Computational Economics*.
Working Paper 1. Iowa State University Economics, 2003,
[56] Martin, R. and Sunley, P.: *Complexity Thinking and Evolutionary Economic Geography*.
Journal of Economic Geography **7**(5), 573-601, 2007,
[57] Lucas, R.E.: *Econometric Policy Evaluation: A Critique*.
In: Lucas, R.E., ed.: Studies in Business-Cycle Theory. Cambridge, MIT Press, pp. 104-130, 1976,
[58] Van Bergeijk, P. and Berk, J.M.: *European Monetary Union, the Term Structure, and the Lucas Critique*.
Kyklos **54**(4), 547-556, 2001,
[59] Caschili, S; Ferrari, C.; Medda, F. and Parola, F.: *Co-operation in Liner Shipping: Managing a Small World Network of Agreements*.
International Conference ECONSHIP2011, Chios, 2011.

PREGLED INDUSTRIJE POMORSKOG KONTEJNERSKOG PRIJEVOZA KAO ADAPTIVNOG KOMPLEKSNOG SUSTAVA

Simone Caschili[1, 2] i Francesca Romana Medda[2]

[1]UCL QASER LAB, University College London
London, Velika Britanija
[2]UCL QASER LAB, University College London
London, Velika Britanija

SAŽETAK

Razmatramo li svjetsku industriju pomorskog kontejnerskog prijevoza kao sustav, opažamo kako veliku ulogu u postizanju utjecajnih pozicija i rastu tržišnog udjela ima velik broj neovisnih racionalnih agenata poput lučkih uprava, prijevoznika, brodarskih tvrtki i proizvođača robe. Industrija brodskog prijevoza se može, s tog gledišta, definirati kao adaptivni kompleksni sustav sastavljen od relativno neovisnih dijelova koji konstatno traže, uče i adaptiraju se svojoj okolini, dok njihova međudjelovnja oblikuju prepoznatljive oblike. U ovom radu razmatramo industriju brodskog prijevoza kao adaptivni kompleksni sustav. Iako su adaptivni kompleksni sustavi primjenjivani u proučavanju bioloških i društvenih sustava, njihova primjena u pomorskom prijevozu je oskudna. Stoge ja naš cilj u ovom radu navesti literaturu koja pristupa međunarodnoj pomorskoj industriji sa stajališta adaptivnih kompleksnih sustava. Također navodimo neke od ciljeva koje se može postići primjenom pristupa adaptivnih kompleksnih sustava posebno na industriju kontejnerskog prijevoza. Konstrukcija trajnog ontologijskog okvira pružit će opsežan pogleda na pomorsku industriju te omogućiti ispitivanje stabilnosti i učinkovitosti tog okvira na unutarnje i vanjske udare.

KLJUČNE RIJEČI

međunarodna trgovina, industrija pomorskog kontejnerskog prijevoza, adaptivni kompleksni sustav