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Features and mechanisms of multi-airport logistics system

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Abstract. This paper presents the past of the Multi-airport Logistics System (MLS) with literature reviewing, and illustrates the development of MLS with the discussion on its features. The features of the MLS are discussed by utilizing case studies on the Northeast MLS in the U.S. with the application of complexity theory. Aggregation, non-linear development, flows of the sources, and the target diversity are the four features of the MLS as a Complex Adaptive System. Compared with existing studies, the features of the MLS may better explain the power of collaborative development of the MLS, and provide a basis for future study on the collaborative development mechanism of the MLS.

Key words. Multi-airport Logistics System, Complex Adaptive System, Features, Airport Cargo.

1. Introduction

Multiple Airports (MA) refers to two or more airports that serve a certain area. The Great London Area, which is the most famous example of Multiple Airports Region (MAR), includes—among others—five main airports [1].

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Multiple Airports System (MAS) is a very useful measure to match the needs and to reduce the congestions of the core airport(s) in the MAR. Bonnefoy found that the development of the MAS is an essential mechanism to help the world air transportation systems meeting future demand [2]. Recently, empirical studies in U.S., Europe, and Asia have revealed that the creation of the MAS can sustain the competitiveness of airports and a region [3],[4].

Nowadays, with the second round of industrialization worldwide, the role of air cargo, as the global trade link, is becoming more and more prominent. Therefore, the discussion on cargo issues of MAS has gradually increased, so does the Multi-airport Logistics System (MLS)[5].

In this paper, the literature on MAR, MAS and the MLS are reviewed, and the features of the MLS with the application of Complexity theory are discussed. First, this paper reviewed the related literature on the MAR, MAS and the MLS. Second, this paper chose the most complex MLS from the six U.S. MLSs, the Northeast MLS, for case study with the applying of the Complex Adaptive System (CAS) theory. Then, this paper discusses the features of the MLS. Finally, this paper frames some suggestions for future research.

2. Reviews on the MLS related literature

Since the 1920s, discussions on the MAR have been developed from the views of airports, airlines, and air passengers. Previous literature discussed the connotation, formation and the development of the MAS. However, research on the MAR focused on the perspective of cargo as a system, a complex system is still relatively limited.

2.1. From the MAR to the MAS

Related studies on the MAR can be traced back to 1920s, and focus on the discussion of air routes service between airports within the Los Angeles and the San Francisco Bay Area [6]. With the rapid growth in air traffic worldwide, the Los Angeles World Airport (LAWA) could not meet the rapidly increasing demand for air service. Hence, a second airport in the LAWA service area was studied. It is suggested that maximum utilization of satellite, or secondary airports in metropolitan areas could reduce aircraft congestion and flight delays by examination of 365 satellite airports in 23 largest metropolitan areas (large hubs).

Although, the definition of the MAS considers the cargo transportation, the definition of "Metropolitan" is founded on the principal of affordable passengers' access. Richard de Neufville illustrated the most widely used concept of the MAS [7]. The MAS is the set of airports that serves airline traffic of a metropolitan area, without regard to ownership or political control. The definition focuses on significant airports, typically those that serve more than a million passengers a year, or a comparable amount of freight (about 100,000 tons, in workload units). Bonnefoy defined several critical items for the MAS, with more attention focused on passenger traffic,[2] as shown in Table 1.

Table 1. Key Items Definition on the MAS

Name	Definition
Multi-Airport System	A set of two or more significant airports that serve passenger traffic in a metropolitan region
Significant airport	An airport that serves more than 500,000 passengers per year and 1% of the total passenger traffic in a metropolitan region
Primary airport	An airport that serves more than 20% of the total passenger traffic in a multi-airport system
Secondary airport	An airport serving between 1% and 20% of the total passenger traffic served in the multi-airport system (and serving more than 500,000 passengers per year)
Emerging secondary airport	An airport that serves less that than 500,000 passengers per year or less than 1% of the traffic in the multi-airport system and that exhibits early signs of emergence (i.e. airport infrastructure improvements, entry of a low-cost carrier)
Under-utilized airports	An existing airport located in a metropolitan region and that serves less than 500,000 passengers, or 1% of the total passenger traffic served in the multi-airport system.

2.2. Development of the MAS

The studies on the formation of the MAS mainly focused on the discussion of air passengers' airport choice. Although the literature on airport choice, from cargo shippers' perspective is limited, there are many studies on the factors determining port choice by marine port cargo users. It seems reasonable to assume that from a cargo shippers' point of view, there is ultimately a relationship between airport selection and marine port selection. The results from marine port selection studies, therefore, provide some basis for airport selection by 'cargo shippers'.

2.2.1. Airport choice by passengers The dynamics of the MAS are the result of decisions made simultaneously by airports, airlines and air travelers [8]. Bonnefoy, de Neufville, and Hansman found that airport passenger choice is mostly driven by the evolution of the MAS [2].

Passengers' choice in the MAS, therefore, is of the most interests to transport researchers, local governments, airport authorities and airline companies. There are many MASs in different parts of the world, such as San Francisco Bay Area the Washington/Baltimore Area , and the New York/New Jersey Area in the U.S.; the Great London Area in the U.K. and the Hong Kong-Pearl River Delta Area in China . Among these MARs, the San Francisco Bay Area is the most widely discussed MAS. Literature on air travel related choice in the MAS focuses on the Multinomial Logit Model (MNL) , Nested-Logit Model (NL), Cross-Nested Logit Model (CNL), and the Mixed Multinomial Logit Model (MML), etc.

Passengers typically choose among various airports within the MAS based on a series of airport attributes. There are two categories of factors affecting passenger.

The flight related characteristics factors include airfare, flight frequency, the number of stops, and aircraft type, etc. The airport related characteristics factors are airport access mode, access cost, and airport facilities, etc. Airfare and the service access are considered the two most important factors.

2.2.2. Airport choice by shippers Shippers typically choose the airfreight forwarders for cargo shipment. Forwarders compare the different modes of transportation for shipment, such as trains, trucks, air, and marine, to achieve the most profit margins at the right place and the right time. In this paper, therefore, the movement of high-value cargo and lightweights' perishables will be only considered, which must be delivered by air, as well as shippers which use air transport.

Past studies focus primarily on two types of potential determinants in port selection: quantitative factors and qualitative factors. Quantitative factors refer to route, cost, and service. Qualitative factors include ease of shipment, reliability, availability, flexibility, and the level of cooperation . Yeo, Park, and Kang found that ease of shipment, connection to hub port and efficiency of hinterland network, are the most important group factors. Tongzon emphasized that efficiency is the most important factor followed by shipping frequency, infrastructure, and location.

Airport selection by cargo shippers is an ultimately an issue related to marine port choice. In port selection, the hinterland is larger than in the passenger market, and the selection activities center on economic gravity and industry clusters. These conclusions provide a basis for our discussion, therefore, on MAR in view of cargo transportation.

2.3. Emerging of the MLS

The MAS has been the topic of an increasing number of studies over recent years in the academic and commercial area. Since 1987, there were serial studies on airport choice within large metropolitan areas. During the last decades, the airports have been substantially transformed into a dynamic and competitive industry. Fortunately, the development of the MAS poses several challenges regarding planning and development. There are two strategic points of view on the MAS: the financial-economic issues and the infrastructural-planning issues.

Curiously, there is relatively limited literature on the MAS in the perspective of logistics. de Neufville represented that those significant airports with more than a million passengers a year, or have a comparable amount of freight, are the key airport that comprise the MAS. However, numerous literatures on the MAS only discussed passenger related issues, while limited literature addresses cargo . Emphasis on the MAS, in the perspective of logistics, is still weak for one or more of the following reasons. First, almost 60% of air cargo moves in the belly of passenger flights. Hence, air cargo was considered as an adjunct to passenger transportation. Second, air passengers are independent selection and decision makers in the MAS. However, only freight forwarders and independent shippers are engaged in regular port selection. Also, independent shippers sometimes choose freighter forwarders with the only concern being the right place, right cargo condition, and right time

at a suitable price. Third, cargo handling is no more profitable than passenger handling. According to Van Dender's research, airport's aeronautical charges are often based only on aircraft weight. Therefore, airport developers and managers pay more attention to passenger handling than cargo. Last but not least, all-cargo carriers have conducted approximately two-thirds of the cargo activity (according to National Plan of Integrated Airport Systems, 2005-2009). The demand for discussion on the Multi-airport Logistics System (MLS), therefore, has increased with the market maturation. However, studies of cargo transportation choice were centered on intermodal and carrier selection, rather than addressing the more specific question of airport choice in the MAR or discussion on the MLS.

The MLS is an integrated complex formed by a set of significant airports, logistics parks, and Free/Foreign Trade Zones, within all sectors of the air cargo supply chains in a city cluster, as in Figure 1, in which, individuals, firms, and organizations are related to the supply chain of air cargo, which constitute the nodes in the network.

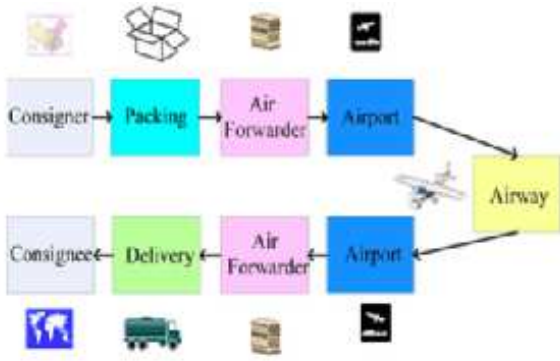


Fig. 1. Sectors of the air cargo supply chain

3. Applying of the CAS

In this part, a MLS for case study is selected. And then, the CAS theory to the case study is applied.

3.1. Case selection

There are six clusters of airports in the U.S., i.e. the Seattle MLS, California MLS, Texas MLS, Florida MLS, Great Lakes and Ohio River Region MLS, and the Northeast MLS.

To highlight the complexity of the MLS, the most complex one is chosen, the Northeast MLS, for case study. There are mainly five airports in the Northeast MLS, New York/Kennedy Airport (JFK), New Jersey/Newark Airport (EWR), Pennsylvania/Philadelphia Airport (PHL), Massachusetts/Boston Airport (BOS), and Washington, D.C. Dulles Airport (IAD), as shown in Figure 2. The traffic data

of airports in the Northeast MLS is in Table 2.

Table 2. Traffic Data of Airports in the Northeast MLS, Year 2014

City/State	Passengers	International Freight	Domestic Freight	Mail	Total Cargo	Traffic Share
New York NY, JFK	53 254 533	1 002 569.0	220 183.0	81137.0	1303889.0	39.0%
Newark NJ, EWR	35 610 759	230 348.0	376 476.0	33106.0	639930.0	19.1%
Philadelphia PA, PHL	30 740 180	123 014.0	243 459.0	26033.0	392506.0	11.7%
Boston MA, BOS	31 658 351	82 143.0	183 363.1	10016.5	275522.6	8.2%
Washington DC, IAD	21 420 385	174 035.0	81 970.0	11730.0	267735.0	8.0%
Hartford CT, BDL	5 875 801	—	—	2323.0	105310.0	3.1%
Baltimore MD, BWI	22 312 676	2 186.0	98 303.0	4664.0	105153.0	3.1%
Manchester NH, MHT	2 095 674	2.0	72 287.0	—	72289.0	2.2%
Richmond VA, RIC	3 352 651	—	—	654.0	52862.0	1.6%
Harrisburg PA, MDT	1 289 487	17 743.0	31 179.0	—	48922.0	1.5%
Norfolk VA, ORF	2 967 887	—	—	1.5	25232.0	0.8%
Albany NY, ALB	2 457 080	—	—	5821.6	17694.6	0.5%
New Windsor NY, SWF	309 357	22.0	13835.0	—	13857.0	0.4%
Allentown PA, ABE	612 650	—	—	—	13635.0	0.4%
Warwick RI, PVD	3 566 480	—	—	—	12396.0	0.4%

3.2. Applying of the CAS

Complexity theory can explain any complex system. Complexity theory has been applied to topics ranging from the transmission of cultural to the growth of economics, and even to the braiding of rivers. In 1995, Holland discussed the CAS with the idea of "adaptation builds complexity". The CAS emphasizes the complex

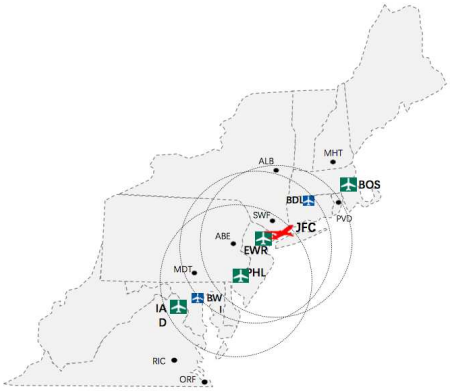


Fig. 2. Geographical Feature of Airports in the Northeast MLS

relationship between the agents and within the system, the microstructures, and the macrostructure. Aggregation, nonlinearity, diversity, and flows are the four fundamental characteristics of any CAS. Meanwhile, the CAS has three mechanisms - tagging, internal model and building blocks.

The formation of the MLS is an aviation industry management issue related to airports, airlines, etc. In 2000, a series of questions was developed to guide researchers and management analyst to use the CAS framework. In 2005, six selected questions were adapted from former study of aviation management and found that the CAS is a new lens in which to guide research focused on the institutional and a networked world within the aviation industry.

The coordination of the MLS is a supply chain management question related to air cargo. Choi, Dooley, and Rungtusanatham sought to extend the application of complexity theory to issues in the management of supply networks and found that the supply network should be a complex adaptive supply network. Surana, Kumara, Greaves, and Raghavan discovered that the complexity, flexibility and adaptability in the collective behavior of the supply chains can be accomplished by importing the mechanisms of the CAS. Pathak, Day, Nair, Sawaya, and Kristal found that the CAS perspective could help in enriching the SCM discipline. Li, Yang, Sun, Ji, and Feng proposed the evolutionary model of complex adaptive supply network based on the CAS and the fitness landscape theory.

The evolution of the MLS is an industrial cluster issue related to the region governments, upstream and downstream industries, etc. Czamanski and Ablas discussed industrial clusters and the complexes by comparisons. Feldman, Francis, and Bercovitz discovered that entrepreneurs are critical actors in the development of clusters as a CAS.

4. Features of the MLS

From the view of each agent, the MLS is a self-organizing system and does not occur in a linear or sequential manner. Character tagging guides the aggregation

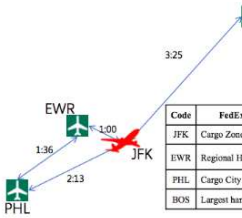
of agents with diverse targets. The flows of the sources enhance the non-linear interactions between agents and the surroundings. Agents gain extensive experience from the interaction. They store, refine and pick up the experience as building blocks. They use these building blocks to build an internal model to predict the future trends and develop strategies for business development. These four features and three mechanisms make for a diverse MLS. The behavior of the MLS is emergent. Moreover, the emergence leads to the formulation of new, unexpected structures, patterns, properties, or processes in a self-organizing system. These features and mechanisms in the emergence of the MLS can then be utilized the third phase of multiple cases study.

In the MLS, there are two types of aggregation and the agents gain experiences from the interaction with other agents and the environment, which has been discussed before. However, the non-linear development, flows of the sources, and the target diversity are still not being explored.

4.1. Non-linear development

The major factor affecting the formation of an ordered internal complex structure is the non-linear interactions between agents. Active adaptation of the agents is the result of the non-linear interaction. Shippers, forwarders, integrators, air carriers and airports are relatively independent agents in the MLS. These agents have a remarkable, creative and proactive adaptation. The cooperation between agents is essentially a multi-objective, multi-layered, and non-linear interaction behavior.

In the Northeast MLS, the layout of the integrators at major airports is somewhat complex, as shown in Figure 3. Both FedEx and UPS have on-airport cargo handling facilities at JFK, EWR, PHL, and BOS. EWR is the FedEx Newark Regional Hub. Moreover, PHL is the second-busiest UPS facility in North America, with regard to daily flights. FedEx is also the largest cargo handler at BOS, while UPS ranked second. There is also a UPS cargo center at JFK. However, these four major airports can be considered as a signal node in the cargo network due to the close proximity. The maximum drive time between most of these major airports is less than six hours (i.e., between BOS and PHL), while the minimum is about one hour, between EWR and JFK.



Code	FedEx	UPS
JFK	Cargo Zone D	UPS Cargo Center, located in Cargo Zone C
EWR	Regional Hub	Package handling and distribution center in the South Area of the airport
PHL	Cargo City	Second-busiest UPS facility in North America, in terms of daily flights.
BOS	Largest handler	Located between the American and United maintenance facilities.

Fig. 3. Car Driving Hours between Airports in the Northeast MLS

Table 3. Traffic Data of Airports in the Northeast MLS

Code	Passengers		Cargo			Movements
	International	Domestic	International	Domestic	Mail	Passenger & Combi
JFK	28 248 253	25 006 280	1 002 569.0	220 183.0	81 137.0	400 074
EWR	11 848 080	23 762 679	230 348.0	376 476.0	33 106.0	365 702
PHL	4 537 605	26 202 575	123 014.0	243 459.0	26 033.0	404 857
BOS	4 992 225	26 642 220	82 143.0	183 363.1	10 016.5	331 670

To analyze the reasoning for the layout or the key factors affecting the decisions of FedEx and UPS, this results in a series of non-linear interactions. EWR is the express carriers' major hub, and provides fast, efficient air-sea connections. As shown in Table 3, EWR had the majority of the all-cargo traffic movements and the highest domestic cargo turnover volume among these four airports in 2014. That meets the definition of a FedEx Regional Hub. EWR is right in the center of the Northeast MLS. Moreover, EWR is not the busiest passenger airport in the region, which may be the main reason for integrators' airports selection. PHL is only one and a half hours away from EWR. PHL is right in the center of a cargo-favorite hinterland in the U.S', which has the largest, densest population, and the most "airfreight eligible" commodity manufacturers within a 12-16 hour's truck drive, that meets the development strategies of UPS. Compared to the EWR airport, UPS faces less threat from FedEx in PHL, which is a critical factor in UPS's handling center selection. All these agents perform as the non-linear interaction.

4.2. Flows of the Sources

Agents are the nodes, and the interactions are the edge in the MLS, which form a network with flowing elements. The flows of various materials, energy and information result in the non-equilibrium of the MLS. In the MLS, the flow of human resource, capital, technology and the information promotes the innovation. The transformations of the innovation driving in the MLS continuously generate new energy, constitute a complex flow of resources, and encourage the development of the regional economy in the society.

The flows of the sources obviously perform as the "air drayage", which means the movement of air cargo via truck. According to the Air Cargo Executive Summary of Pennsylvania 2002, a significant amount of air cargo from surrounding states that are transported into Pennsylvania for air transit via the Commonwealth airports, as shown in Figure 4. The export air cargo in Pennsylvania to surrounding states was 330,000 tons in 2002. Moreover, Pennsylvania received 276,000 tons of air cargo from the surrounding states in 2002. Pennsylvania's primary drayage partners are New Jersey, New York, and Ohio. In Massachusetts, there are also flows from the sources. It is easy for Massachusetts's consumers and industries access other major

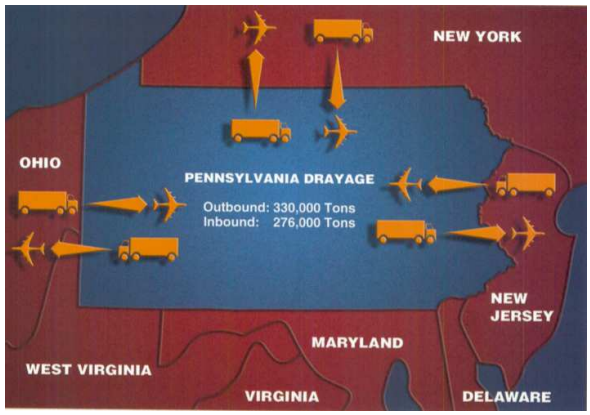


Fig. 4. Pennsylvania Drayage in 2002

freight airports outside of the state. PVD, MHT in the eastern region and BDL in the western region are all within an easy truck drive (according to Identification of Massachusetts Freight Issues and Priorities by Massachusetts Freight Advisory Council).

The economic and social impact of air cargo is the results of the elements flow. For example, airfreight is critical to the Massachusetts economy since it is a center of high-value manufacturing and a leader in the knowledge economy sectors, such as biotechnology, pharmaceuticals, and information technology (according to Massachusetts Department of Transportation Freight Plan in September 2010). Also, new cargo facilities and business practices in both on-airport and the redevelopment of an off-airport cargo village increase job growth. Due to cargo development, JFK was described as a vital piece of NYC's economy. According to the JFK Air Cargo Study, air cargo development at JFK created 50,000 jobs, $3.0B in wages, and $8.5B in sales. Also, at EWR, UPS employs about 10,261 workers, and FedEx employs about 5900 workers.

The flow of information is the primary way in which to promote the interaction of the agents in the MLS. Decision-making consultation is an effective means of obtaining information on cargo development, and a mechanism used to enhance the flow of information. For example, a consultant, who has over 20 years of experience in aviation consulting, especially on air cargo development, may provide advice not only on cargo development, but a combination of strategic and regulatory matters related to airfreight. In addition, they provide consulting services to airports on industry competition and airport logistics development strategies. In most instances, consultation on air cargo development strategies is collected from the previous projects, which promote the flow of information to the client and within the industry.

4.3. Target diversity

Diversity is another principal feature of the CAS. Target diversity is the result of the continuous adaptation of the agents. Different agents, with various goals, take

different strategies to interact with other agents and their surroundings. In the MLS, the target of the air carriers is to transport increased cargo volumes. The target of the airports is to compete for their share of the air cargo market. In addition, local governments desire to enhance their economic environment and create more and more jobs. The interactions between these different types of agents are extremely complex.

According to the JFK Air Cargo Study, several carriers found that airside connectivity needs were unmatched at JFK. Carriers recognized that EWR offered various operational advantages as compared with JFK. As a result, they first to considered EWR to be a logical choice of air cargo development. However, due to integrator operations at EWR, and the ability to connect with a diverse range of other carriers, they found EWR to be a limiting choice for development options. Beyond FedEx, EWR's cargo operations are driven by large niche market demands such as New Jersey's pharmaceuticals industry. However, and notably, some major forwarders that once operated twin facilities at both EWR and JFK relegated their former cargo facilities to offices while concentrating their regional warehouse operations in proximity to JFK. In this situation, SWF is a superior alternative to JFK and EWR. However, the use of SWF was also complicated by the absence of forwarders, the distance from the city, and the inability to interline cargo with other carriers. Finally, operators opted on other gateways, such as PHL. Carriers and forwarders agreed that international freighter operators no longer considered New York an inherent first option, and some carriers abandoned the New York airports for other airports such as IAD close to Washington.

5. Concluding remarks and suggestions

The discussion on air cargo development in the MAR is becoming broader, so as the emerging of MAS and MLS. The four fundamental characteristics of the MLS are aggregation, nonlinearity, elements flows, and target diversity. Therefore, future studies on the MLS should be carried out within the CAS framework, such as the discussion on behavior patterns of the MLS, the coordination and cooperative development mechanism of the MLS, and etc.

Based on the complexity of MLS, this paper recommends agents to enhance coordination and cooperative development of the MLS. Cooperation within the MAS should focus on the co-operation of air traffic control and ground holding technologies at various airports [38], and the organizations coordinated management of several airports. The collaborative development models, strategies and policy of the MLS should be discussed with further analysis cases studies.

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