System Dynamics Approach Applied in Civil Aviation Management

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ABSTRACT

This paper reviews the literature pertaining to the application of System Dynamic (SD) approach in the civil aviation industry. Since civil aviation industry are faced various challenge to be a competitive transportation mode, the burgeoning field of aviation economy is an addictive and interesting area for both researchers and practitioners. System dynamic explores and explains economic activities within the civil aviation industry from the perspective of system and structure, which differs from many other models and this paper is presented in an attempt to investigate the employment of SD and its strengths, weakness and prospect within the civil aviation market.

KEYWORDS
Aviation Market, System Dynamics, Forecast, Airport, Airline.

INTRODUCTION

System dynamics (SD) was initially developed in the 1950s combining the system theory, information science, organisational theory and control theory together, to model the nonlinear dynamics of complex systems by utilizing Casual Loop Diagram (CLD) and quantitative Stock-Flow Diagram (SFD), which provides something different compared to the traditional modeling approaches, regarding either inters of insight or coverage of the problem research. SD can be used to identify key driving forces, and understand interactions among agents, analyse reaction in various scenarios, then give relatively rational strategy and policy, which has been applied in a various areas, such as society (Dishion et al., 2004;), economy (Xu et al., 1989; Patrakeeva et al., 2016; Elsawah et al., 2017), industry (Mehrjoo et al., 2015; Zhang et al., 2017; Xu et al., 2015), regional and urban development (Forrester J W, 1987; Wu et al., 2016), agriculture(Fu et al., 2012; Chapman et al., 2016), ecology (Crookes et al., 2013; Hashimoto et al., 2013), population(Weller F et al., 2014; Pérez et al., 2015; Wu et al., 2016), sustainability (Iandolo et al., 2018; Tan et al., 2018; Cheng et al., 2018), business management (Duranencalada et al., 2012; Swanson J., 2002), project management (Faezipour et al., 2018; Lee et al., 2018)and military(Moffat J, 1996; Fan et al., 2010).

The air market is a complex economic system involving interactions between loads
of agents like government, stakeholders, investors, managers, passengers and local communities. It has been proved as a susceptible system influenced by circumstance such as economic events, industrial agreements, new government policies, technical innovations and business model innovations (Schmitt et al., 2016). Since Abbes introduced SD modelling method in 1994 into transportation system and compared it with traditional transportation model by listing advantages, many researchers began to explore and investigate issues aroused in the air market through utilizing SD, like demand prediction, casual analysis, structure analysis, trend analysis. SD has been certified as a powerful and suitable method and a support tool for the aviation academia and practitioners, owing to its more systematic and comprehensive thinking in scope (James M et al., 2015; Gary 2010; Maier1998) and it can bring the opinions and thought of different stakeholders and experts together and simulate results under various scenarios considering the feedbacks to optimize policy implication.

The aim of this paper is therefore to review papers focusing on the aviation market to analyze and solve economic problems and issues by utilizing SD model according to the time of significant policies or agreements practiced in, and to summarize the merits and drawbacks of SD approach. The paper structures as following: the second part will be the application of system dynamics in air market forecasting where generates the most papers, and next will be the application in the airline industry followed by the airport industry. Then is the discussion and the last section is a conclusion.

**SYSTEM DYNAMIC APPLIED IN AIR MARKET FORECASTING**

Demand forecast plays a crucial role for air transport planning and is a complicated progress as it at different level should ideally take of corresponding influences and factors into consideration. Diversity of measures and techniques have been used in the area of aviation system forecast, like Exponential Smoothing Method (Samagaio et al., 2010), Markov Model (Sun X, et al., 2016), Regression Method (Shcherbanin 2016), Gray Model (HSU 1998), Gravity Model (Grosche 2007), Logit model (Başar 2004; Harvey 1987) and other Econometric Model (Fildes et al., 2011). Some academies combine several methods but not relying entirely on single models in order to weaken the drawbacks inherited (Xiao et al., 2014).

Quan(1996) utilized the SD methodology to forecast the demand on air transportation system in China from two dimension by establishing a macroscopic China’s Socio-economic Development Model (CSEDM) and a microscopic China’s Air transportation System Development Model (CATSDM). In CSEDM, the potential air demand is referred as the function of some socio-economic variables involving industry, social, infrastructure, population, which determine the disposition and means of travel. The CATSDM comprises of the airlines, air routes and airport sectors, consisted of several air transportation variables such like airfare and annual delay. The discrepancy of result of air demand forecast from these two models is regarded as the mismatching between development of China air transportation system and China’s growing economy. Therefore, this research examined various policies variables to balance this discrepancy and get the quantitative suggestions for such policies.
As Quan applied SD as a living laboratory which can implement polices into the real system, Lyneis (2000) borrowed commercial jet aircraft industry case examples in his consulting work to systematically illustrated and demonstrated the advantages of SD with the comparison of forecast results between SD models and other statistical models like trend extrapolation models and regression models. This paper emphasized the important of capturing the industry structure when do the forecast and summarized three major advantages of SD models as following:

(1) Can provide more reliable forecasts of short- to mid-term trends than statistical models;
(2) Enable managers to understand the primary causes of industry behaviour, and thereby allow identifying key sensitivities for forecast and early detection of changes in industry structure;
(3) Allow the determination of reasonable scenarios as inputs to decisions and policies.

Suryani et al. (2010) established a SD model to forecast the future air passenger demand in Taiwan Taoyuan International Airport in order to research the necessity and quantitative requirement of the runway and passenger terminal expansion. This paper identified several dominant feedback loops and validated this SD model by checking the comparison between the simulation result and historical date. Suryani found that airfare impact, level of service impact, GDP, population, number of flights per day and dwell time play an important role in determining the air passenger volume and designed two mixed scenarios by structure scenario and parameter scenario to achieve the different demand of air passenger and the additional expansion requirement of runway and terminal.

Weiling Liu (2015) has built the SD forecast model to predict the demand of the air-rail mode transportation based on the analysis of passenger flow and the casual relationships between factors affecting demand. The expansion of SD into the air-rail mode is meaningful for infrastructure planning and traffic arrangement for the development of this modern transport mode. Yaqing Chen (2009), and Xinhui Ren (2015) also stated the superiority of the SD over the traditional models and applied it to satisfy the forecast requirement in reality. Fuqing Dai (2009) extended SD approach to do air fleet forecasting.

SYSTEM DYNAMICS APPLIED IN THE AIRLINE INDUSTRY

AIRLINE ENTRY AND ALLIANCE

Kleer et al, (2008) utilized SD model to analyse the impact of airline entry on national routes within different scenarios. Based on the stocks and flows theory, airline configuration, policy, attractiveness and demand were decrypted to structure the entire model. In this paper, data and monetary information of German Antitrust law suit between Lufthansa and Germania were employed as a reference case to calibrate the SD model and simulate strategic movements of airline. This paper also confirmed the hypotheses that dynamics in airline markets were driven partially by effects of airline entry and exit on a city pair. Additionally, the paper also provided suggestions for carriers (Incumbent network carrier or low cost carriers) to against the
impact of other carriers entering the market form the perspective of optimizing cost structure.

Agusdinata et al. (2002) employ the Casual Loop Diagram (CLD) to detect the driving forces for airline alliances and then examine the inherent stability of alliances under a global economy scenario. The analysis demonstrates how CLD can be developed to illustrate the complex behaviour within the economic cycle. The original paper describes the relationship between the transition economy and airline alliances, which indicates that globalisation creates not only a more hostile and competitive market environment for airlines but also generates opportunities. Significant factors including External stability drivers (e.g. cyclic economy, anti-trust legislation, hub airport congestion) and internal stability factors (e.g. alliance’s organisation and inter-organisational relationship) were considered in this paper. Although neither data analysis nor scenario simulation were conducted subjected to the availability, this paper provides foundation for quantitative analysis and sophisticated models for further studying the behaviour of global alliance and managing the alliance and achieving better performance.

The airline sector initially experienced changes as the consequence of airline deregulation, privatisation, and globalisation trends (Barry et al., 2008). A stream of previous literatures have explained and studied major characteristics in the deregulated airline industry like airline entry and alliance issue (Oum et al., 1997) involving network construction and fleet planning, revenue management, codeshare, market competition, service quality and consumer welfare.

AIRLINE CYCLIST

Liehr, M. (2001) utilized SD model together with statistical forecasting model to interpret and identify the key factors for cyclical behaviour observed. Cyclic is a normal phenomenon in airline industry and is driven by two primary reasons, they are manufacturer delay and the delay of awareness of surplus passenger capacity. This casual relation has been depicted in this paper by using CLD approach. The data of Lufthansa German Airline has been used to do estimation and scenarios simulations and propose leverage points to managing cyclic in many processes like aircraft ordering, network planning and making capacity flexible.

Pierson and Sterman (2013) extended the boundaries of previous studies and utilized system dynamic model to explore the cycle of airline industry earning since deregulation in the US. An overview of causal relationships within this system was concluded and presented in the original work for a better understanding of their research. Notably, the impacts of endogenous capacity, demand, pricing and costs on airline profit cycles has been investigated and Markov Chain Monte Carlo methods makes SD Parameter estimation much more reachable. They found that price setting surprisingly play a crucial role in stabilizing industry profit but aircraft acquisition was not as significant as expected in determining profit cycle.
SYSTEM DYNAMIC UTILIZED IN THE AIRPORT INDUSTRY

Biesslich P et al., (2014) utilised SD methodology to build a generic model involving elements both from operational and economic aspects. Data from Hamburg Airport were taken to assess the functionality of the model. The SD approach is proved to be useful tool to show the dynamics of aircraft/customer movements, number of passengers, capacities, infrastructure development and cash flows. This work focus on the long term development of an airport and provides an insightful view for airport’ infrastructure planning and development.

AIRPORT REVENUE

Qin (2016) depicts a diagram for the whole structure of airport revenue system involving all the agents and users so as to optimize the airport system through utilizing SD approach based on a better understanding of the relation between airport revenue system and the governments, airlines, airports, passengers and even HSR (High Speed Railway). Qin investigated the long-term impact of price regulation on airport revenue within different regulation regime, Nanjing and Perth, and examined the effect of HSR and LCC on airport revenue by building a decision support system based on the SD model. The simulation results indicate that government regulation plays an essential role for airport revenue optimizing as airport charging rate makes great contribution to revenue. However, when competing with the HSR, airports and airlines should cooperate to offer higher quality service to be more competitive in the short-haul market. Further more, it might be wiser and more practical for airports to apply tendentious charge rates for different types of carries to maximize revenue, particularly when LCCs are serving in the market.

Steverink (2011) utilized a SD approach together with the traditional discrete choice method to help enhance the understanding of airport choice mechanism and detect the underlying factors of the asymmetric response for the ticket tax policy. Actually, airport choice has strong association with airline strategies which influence the customer behaviour directly, a conceptual model is thus constructed in his work to illustrate the relations. This paper showed the information and characteristics of airports had significant impact on passenger choice and were spread through three mechanism including marketing, experience and word-of-mouth mechanism. The simulation results of this paper suggest that awareness of alternatives is a significant factor influencing passengers’ response both at the time of the introduction or after the abolishment of the tax.

Minato and Morimoto (2011) developed an SD model to suggest that regional airports run as an ecosystem involving airports, airlines, aircraft, passengers, local governments and local communities and then proposes optimal management strategies to prompt the commercial sustainability of regional airports. The structure of the airports ecosystem was depicted via using CLD to visualize the interactions among variables and important feedback loops. Within this SD model of regional airports system, various management strategies have been simulated to launch for maintaining airports profitable, like fuel tax reductions, airport charge reductions, subsidies for aircraft purchases, profit loss compensation, load factor guarantees and subsidies for airline tickets. The results suggest ticket subsidies for visitors have been
considered as the most desirable strategy for the regional airport ecosystem. This paper also indicates that non-aeronautical revenues contribute positively to regional airport’s financial state and provides novel perspective for airport managers facing multiple business stakeholders to keep profit sustainable.

AIRPORT AND AIRLINE RELATIONSHIP

The strategic interactions between airports and airlines require examination of airports and airline-services in an integrated manner. Minato et al. (2017) examined the coexistence of airports and airlines under the load factor guarantee (LFG) business model via utilizing SD model. LFG means an agreement that airlines and airports negotiate the load factor of local flight with an interference of government’s subsidies for the deviation between actual and agree-upon load factor, which is a policy launched by the government to make the regional air transportation profitable in Japan.

The interaction between airline and airports within the LFG framework in Minato’s paper was presented in original research. The model tested by using the data collected from Haneda—Noto flights was completely capable to duplicate past behaviours and reproduce macroscopic system behaviours for further simulation. And then different scenarios were examined including demand adjustment, target load factor adjustment and their combination. The simulation results show that integrating load factor adjustment and monthly demand adjustment is the essence to successful airline-airport coexistence within this LFG scheme, because the separating adjustments lead to converse consequences for the discrepancies and the symmetry between the financial states of airline and airport.

AIRPORT EXTENSION AND INVESTMENT

Suryani et al (2012) employ the same model framework in Suryani et al (2010) to do air cargo demand prediction and investigate the best time to expand the terminal capacity based on optimistic and pessimistic scenarios analysis. The impact of competition with other airports has been considered in this paper. The result shows that GDP and FDI play a crucial role in demand fostering. And the comparison between varying scenarios simulations indicate that terminal expansion would be delayed to more 12 years in optimistic projection than pessimistic cases.

Miller (2005) has utilized system dynamic model combined with Monte Carlo simulation to assess and weigh the airport capacity expansion strategies of building a second runway and buying the land. Miller et al, (2007) improved the methodology to evaluate the flexibility of expansion and delivery strategies. The casual relations between airport capacity, airport and airline congestion, fare level, service level and passenger demand, flight frequency and airport revenues has been explained in the original study. An air transportation infrastructure investment example was used. Cash flows within various circumstances in this investment project is fully showed, and three infrastructure delivery strategies, such as the level of capacity expansion, the time to deliver and the time for reaching capacity threshold, had been examined and
simulated by Monte Carlo simulation. The results show that smaller increments in capacity and quicker recovery time have better chances for gaining more profitability than other strategies like larger capital expenditures, capacity expansion and infrastructure investment.

**DISCUSSION AND FUTURE APPLICATION**

**LESSONS LEARNED FROM PREVIOUS STUDIES**

Since SD modeling approach was firstly introduced into air market area, researchers are willing to investigate and explain economic activities occurred such as, alliance and airline entry, airline cyclist, airport expansion, airport-airline cooperation, airport revenue sustainability and the influence of environment changing on the development of airports and airlines. The CLD and SFD technique used in the previous literature make the structure of air market system more visible and understandable. And SD approach allows decision makers and researchers to exercise policies and new structure changes at various points in time and quantify result immediately, this capability has made it be widely utilized to evaluate the reasonability and impact of policy and address the strategic issue in air market system, and has been a superior approach proved by some successful applications regarding the airlines and airport industry among industrial, regional and national level. In addition, SD is an advanced approach to explore and investigate the cyclical and sustainability of airline or airport industry which is analogous to the ecosystem.

System dynamics modeling has been deemed to be an excellent approach to explain the complex behavior and tackle some concerned issues in the air market system, some challenges including modeling, data collection, model calibration, policy optimization, validation, and verification facing researchers need to be aware when utilizing it. For instance, no technical standard is proposed to evaluate the improvements when improving the practicality of the mental model and the complicated and tedious simulation for evaluating key factors under different scenarios is another difficulty, especially in a complicated and big-scale system with many key factors. Whereas, due to the confidentiality of the data (operation and production in particular) in airlines and airports industry, the availability of data has become the greatest obstacle to employ SD in the air market system and then might lead to the research stranding on macro-level and be ineffective or invalid to address micro-simulation problems like fleet and crew assignment, passenger choice analysis etc.

**FUTURE RESEARCH DIRECTIONS**

For the future investigation in the air market areas, numerous topics are worthy to explore within the air market system with the consideration of tourism, employment, local economy and even the global economy. The trend of privatization and commercialization of airlines and airports occurred in the air transport system have resulted in the introduction of initiatives and business approaches that focus on efficiency, cost reduction, ancillary revenue generation, profit maximization and,
ultimately, economic sustainability. The benefits of SD model will be more distinct when the decision makers realize the cost implement of polices without the systematical looking and quantity data support.

For further application, we could utilize it together with other theories, modeling and simulation approaches to widen its application range and weaken its drawbacks. For instance, SD modeling mixed with discrete simulation tools may help to understand and explain the dynamics of complicated system much better, and the combining with constrain theory in SD might be beneficial to simplify problems and prompt the feasibility and validity of SD modeling. Moreover, systematic thinking also makes it more feasible and flexible to consider the air transportation problems together with issues in other sectors, like environment, safety and economy. But as we propose to employ SD approach, we should bear in mind that we build model to solve problem through searching information related to the system instead of merely modeling, in other words, as Swanson, J said, SD is used to solve problems, not model a system.

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CONCLUSION

The paper made an attempt to review the application of SD in the air transport market area along with the significant policies events happened in this industry. The reviewed literature was categorized into three section, namely forecasting, airline industry and airport industry. The three themes contain most topics and issues happened in the aviation industry including demand forecasting, airline alliance and entry, airline cyclist, airport revenue, airport expansion and, airport-airline cooperation. Paper utilizing system dynamic were reviewed and other methodologies employed were also mentioned. Based on the review, the advantages and considerations were mentioned when using SD, then the important gaps in the applications of SD modeling approach in the aviation industry were emphasized and, further research and application were also provided. Nevertheless, this review has some limitations. First, different keywords retrieve might result in a different sample of papers. The definition of research in air transport market makes papers available fewer. Second, reviewed work is limited to papers in the air transportation industry, non-peer papers used the same method in the other sector were reviewed, this process might make papers involving valuable SD applications and additional insights missing in this review. While it is expected that this review will motivate interesting development and application of SD and facilitate more constructive and practical solutions in air transportation industry as well as other sectors and thus to benefit the society.
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