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A systematic review of the literature on air transport networks (1973-2021)

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Abstract

This research provides a systematic literature review on air transportation. Three periods are analysed: 1973-1999 (120 papers), 2000-2019 (742 papers), and 2020-2021 (177 papers), with the period 2000-2019 being the main focus. A computer-assisted thematic analysis was conducted using Reinert's method to quantify thematic classes and their prevalence statistically. The evolution of class predominance over time was also analysed. The results highlighted six major thematic classes in 2000-2019, with three reflecting methodologies (i.e., parameter estimation, time-based problems, and optimisation) and the remaining three characterising underlying applications (i.e., co-opetition, business models, and external stakeholder/social view). Classes found for 1973-1999 also discuss optimisation and co-opetition, with the remaining classes focusing on aviation developments in Europe and transportation systems in general. Classes found for 2020-2021 agreed largely to the period 2000-2019, albeit with more well-delineated classes on the COVID-19 pandemic and the connectivity and accessibility of air networks. A correlation of methodologies and applications (2000-2019) identified the ubiquitous use of regression analysis throughout applications and the underrepresentation of complex network analysis and economic modelling in applications associated with the business models and external stakeholder/social view classes. Temporal trends suggest a steady increase in discussions of the parameter estimation class and subclasses related to low-cost carriers in Europe, regional airports, and high-speed rail co-opetition, and a decrease in investigations of airline alliances, deregulation, and privatisation.

Keywords: airline; network; IRaMuTeQ; Reinert's method; systematic literature review.

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1. Introduction

While air transport networks play a central role in trade, tourism, accessibility, and integration among regions as well as in social development and economic growth in general (Zhang et al., 2008; Fu et al., 2010), comprehensive studies of the subject have been scant with no empirical systematic literature review (SLR) being provided. The closest SLR available (Ginieis et al., 2012) offers a view of studies on the general topic of air transport published from 1997 to 2009. However, almost a decade later, its results may not accurately reflect the present state of discussions in this field or the prominence of such discussions, thus leaving researchers and industry practitioners with no clear outlook on air transport networks. With this gap in mind, this research aims to map (1) the many perspectives from which air transport networks have been examined in the literature from 1973 to 2021, (2) the overall prominence of discourses about such perspectives, (3) the temporal evolution of these discourses, and (4) the main approaches undertaken in these analyses, determined by correlating employed methodologies and applications. The remainder of this paper is organised as follows. Section 2 specifies the research design and describes methodological justifications and data collection procedures. The analysis is presented in Section 3, followed by discussions and conclusions in Section 4.

2. Background and methods

An SLR is a methodological approach that offers a clearly defined protocol for identifying, selecting, and critically assessing literature, guided by principles of both methodological and analytical comprehensiveness, rigour, objectivity, and transparency (Tranfield et al., 2003; Dixon-Woods, 2011). As theoretical and methodological foundations for this research, the five steps outlined in Khan et al. (2003) were deployed: (1) the formulation of the research questions (planning the search strategy and devising relevant keywords), (2) the location of relevant studies (identifying repositories and target journals), (3) the selection and evaluation of studies (applying inclusion and exclusion criteria), (4) the analysis and synthesis of the studies, and (5) the reporting of findings and insights. A computer-assisted thematic analysis was employed. Such an approach has been noted to surmount several issues present in traditional (manual) thematic analysis while complying with the core principles of an SLR (Schonhardt-Bailey, 2005; Bicquelet & Weale, 2011). Reinert's method is applied to statistically quantify thematic classes and their prevalence and organise their relationships.

While topic models could have been used, authors of the most popular approaches note a gap between how these models are used and assessed (Blei, 2012; Roberts et al., 2016). Due to concerns about model tractability, topic models maximise a likelihood function, rewarding the model's goodness of fit. Nevertheless, the results produced with this criterion are associated with decreased human interpretability (Chang et al., 2009; Lau et al., 2014). Therefore, analysts have resorted to external model quality assessments, such as "*semantic coherence*" and "*topic exclusivity*". Additional shortcomings include the instability of results across different algorithm initialisation conditions and focusing on full texts rather than smaller contextual units (Roberts et al., 2014).

In contrast to topic models, Reinert's method, an alternative approach to automated content analysis, focuses directly on maximising the internal similarity of words within thematic classes and the differences among such classes, with the stability of the results built-in as the algorithm's stopping criterion (Reinert, 1990). The resulting tree diagram produced by the method represents a hierarchy of thematic classes, with the proximity of classes implying an overlap of the vocabulary used. With these results at hand, the analyst can interpret and conceptualise the meaning of the classes. Lists of the most characteristic content words and most representative text segments, as measured by their χ^2 values, are standard tools utilised in this method (Schonhardt-Bailey, 2005).

A comprehensive search was conducted to guarantee that all relevant research on airline networks would be considered for the literature identification, as not all papers might make this point explicit. General terms in the document titles, abstracts, and keywords were searched for, a procedure that is detailed in the following paragraphs. It was decided to refrain from manual filtering, as this process could be prone to subjectivity and researcher bias. Moreover, given the adopted statistical approach, true outliers should not significantly influence the results—their vocabulary usage should presumably be distinct from that of the central literature, thus confining them to separate classes.

Elsevier's Scopus database was consulted, as it is one of the few databases allowing researchers to focus solely on peer-reviewed material (Compagnucci et al., 2020). Scopus also has a broader spectrum of journals than other databases, such as Web of Science (López-Illescas et al., 2008; Archambault et al., 2009; Mongeon & Paul-Hus, 2016), indexing 50% more social science journals than the latter (Manatos et al., 2017). Additionally, it has been found to present fewer inconsistencies regarding content verification and quality than either Web of Science or Google Scholar (Adriaanse & Rensleigh, 2013).

The terms "*network*" with either "*airline*", "*air carrier*", or "*air transport*" were searched for, including all possible suffixes. The earliest publication found in Scopus is from 1973. However, the period 1973-1999 contained many papers that did not have an online version of their full texts available, or the PDF files presented challenges to text recognition due to low-resolution images. This period was analysed separately, only through papers' abstracts, given these shortcomings. Similarly, due to the statistical approach adopted in the present analysis, in that results are driven by the prominence of discourse, the confinement of discussions on the COVID-19 pandemic in solely two years (2020 and 2021) entails an overshadowed assessment of this theme in the face of more established discussions developed in the previous twenty years (2000-2019). It was decided to analyse this period separately to understand changes in discourse due to COVID-19. Many papers published in 2020 and 2021 seem to have taken the opportunity to include the term "COVID-19", even though the pandemic was not their research's primary concern. This feature prompted the authors to decide on a temporal division rather than a keyword selection for analysing the period.

The main focus on the period 2000-2019 can be justified given an increasing number of publications and the many significant events that took place in that period, which were expected to have contributed to intense transformations and trends in the industry's development (e.g., the terrorist attacks of 9/11, the global financial crisis and increasing jet fuel prices of 2008, expanding low-cost carriers (LCCs) worldwide, and airline mergers and acquisitions).

The search was restricted to peer-reviewed academic articles published in journals containing "*transport*" in their titles, with all possible suffixes, to identify potentially richer and more relevant discussions related to the sector. The abovementioned terms were searched in the titles, abstracts, and keywords of papers included in Scopus on 15 May 2022.

To ensure the quality of the results, only journals with a SCImago Journal Rank (SJR) score in the top two quartiles (Q1 and Q2) in the area "*transportation*" were chosen. After the proposed procedures, the resulting databases were reduced to 120 (1973-1999), 742 (2000-2019), and 177 papers (2020-2021). The SJR indicator is based on Scopus data and encompasses significantly more journals than those considered under the impact factor measure (Falagas & Kouranos, 2008). García-Peñalvo et al. (2010) discuss the advantages of the SJR indicator, such as weighting citations based on the citing journals' prestige, the partial exclusion of journal self-citations, and the broader base of source journals. The SJR score also allows for selecting only journals relevant to a particular field. Last, an inspection of the abstracts and titles of the final corpus was conducted and revealed a minimal presence of outliers.

Analyses were conducted in the software IRaMuTeQ (Ratinaud, 2014). Reinert's method focuses exclusively on content words (i.e., nouns, verbs, adjectives, and adverbs), with grammatical endings removed to produce "*lexemes*". Further corpus processing includes lowercasing words and removing accents. Together with the recognition of word syntax, all functionalities are readily available in IRaMuTeQ. However, more easily interpretable results were obtained in experiments when those steps were conducted using the Python libraries spaCy and Gensim.

Specific syntactic categories were retained in spaCy through part-of-speech (POS) tagging. Following Schonhardt-Bailey et al. (2012), idiomatic expressions, e.g., "*air transportation*", were transformed into single terms, a functionality available in Gensim but not in IRaMuTeQ. The procedure was applied twice to capture compound concepts such as "*low-cost carrier*". Another advantage was the differentiation of concepts composed of the same words in a different order (e.g., "*airline network*" vs. "*network airline*").

2.1. Broad vs. detailed analyses

A comprehensive analysis of the corpus using IRaMuTeQ was conducted for all three periods. This analysis used the software's standard values of 40 occurrences per text segment, ten terminal clusters, and the 3,000 most frequent forms as an upper bound. A more detailed corpus classification was also sought for the longer period of 2000-2019 to provide further insights. Such a breakdown is seen in Noël-Jorand et al. (1995), who identify subclasses of vocabularies within original classes. However, it is implied that, given a small vocabulary, such clusters were established by these authors manually. One possible automated approach would be to follow Bicquelet & Weale (2011). They conduct a so-called *advanced analysis* in which text segments assigned to a given class of interest can be collectively considered a new corpus. This approach allows Reinert's method to be reproduced self-similarly to refine the results.

Although such a procedure was followed, more coherent classes were produced by following a different strategy, which will be the focus here. The prespecified number of terminal classes in the algorithm was set to a higher number. This change allowed the algorithm to run further down a tree before the stability of its classes was tested. Thus, an advantage was taken of the nested structure of the results to provide additional clues to guide the understanding of class subdivisions. The results produced in this manner enabled a reduction of residual classes, an issue found while conducting an advanced analysis. This issue was somewhat expected, as an advanced analysis must work with a more constrained (and likely less cohesive) set of text segments. In contrast, given the nested structure of the results, it is expected that the upper nodes in a more detailed tree would match the original thematic classes found previously to a considerable degree. To contrast such an approach with an advanced analysis, in what follows, this procedure will be referred to as "*detailed analysis*".

3. Results

3.1. The period 1973-1999

The abstracts of 120 papers were decomposed into 291 text segments, with 242 text segment (83.16%) classified into five classes, as depicted in Figure 1. The classes found were: *operations* (30.6%), an isolated class associated with a methodological vocabulary, focused on optimisation models; *hub-and-spoke network configuration* (20.6%) and *alliances and consolidations* (17.8%), two classes associated with competition and cooperation between and of airlines, offering a market view on air transportation and further featured in the period 2000-2019; and classes *aviation development in Europe* (12.8%) and *development of (general) transportation systems* (18.2%), the discussions of which became vastly scarcer in the following periods. Figure 1 presents the 20 most significant words of each class and their χ^2 values due to space considerations, even though text segments assisted the classification. The same observation applies to corresponding data in subsections 3.2 and 3.3 (Figures 2 and 5). Due to limitations derived from the reduced number of articles and the analysis being restricted to their abstracts, it was decided to refrain from further explorations of this reduced sample—compare the number of text segments from this period (291) with the ones from the following periods (in chronological order, 62,767 and 21,495).

Figure 1. Corpus breakdown (1973-1999).

- Network-centred methods (30.6%)
  - Operations (30.6%)
- Air transportation ecosystem (69.4%)
  - External stakeholder/social view (31%)
    - Aviation development in Europe (12.8%)
    - Development of transportation systems (18.2%)
  - Co-opetition (38.4%)
    - Hub-and-spoke network configuration (20.6%)
    - Alliances and consolidation (17.8%)

Operations (30.6%)		Aviation development in Europe (12.8%)		Development of transportation systems (18.2%)		Hub-and-spoke network configuration (20.6%)		Alliances and consolidation (17.8%)	
Content words	χ2	Content words	χ2	Content words	χ2	Content words	χ2	Content words	χ2
model	51.8	*Europe*	35.3	*discuss*	40.7	*hub*	57.6	*competition*	48.9
aircraft	34.8	*social*	34.3	*road*	37.2	*study*	29.7	*carrier*	37.2
time	34.3	*European*	32.2	*railway*	32.4	*hubbing*	23.4	*alliance*	32.9
flight	27.3	*western*	27.7	*freight*	28.3	*permit*	19.6	*competitive*	28.3
flow	25.5	*community*	20.6	*attention*	27.7	*metropolitan*	19.6	*airline*	23.6
delay	25.1	*aviation*	18.4	*transport*	26.8	*examine*	19.4	*welfare*	22.8
design	23.7	*air service*	18.0	*role*	21.2	*network structure*	18.6	*recent*	19.5
plan	18.9	*regional*	15.6	*group*	18.8	*efficiency*	18.6	*consolidation*	18.1
assignment	18.8	*world*	15.3	*pay*	18.3	*major*	16.8	*share*	16.6
algorithm	18.8	*net*	14.1	*draw*	18.3	*air transportation*	15.7	*increase*	15.5
base	18.6	*authority*	12.7	*conclusion*	13.7	*spoke*	15.3	*price*	15.5
air traffic	14.3	*regulatory*	12.7	*port*	13.7	*enjoy*	14.7	*merger*	15.3
allocation	14.0	*region*	12.0	*ship*	13.7	*United States*	12.9	*focus*	15.3
represent	14.0	*suggest*	12.0	*reform*	13.7	*strategy*	12.1	*partner*	14.2
choose	14.0	*air transport*	11.5	*notion*	13.7	*extent*	11.7	*deregulate*	14.2
minimize	14.0	*country*	11.0	*inland*	13.7	*availability*	11.7	*American Airlines*	14.1
condition	13.9	*liberalization*	10.2	*fit*	13.7	*traveler*	11.7	*Japan*	14.1
demand	13.6	*grow*	10.2	*Asia*	13.1	*deregulation*	11.5	*Delta*	14.1
origin	12.6	*government*	9.4	*alternative*	13.1	*airline*	11.1	*obstacle*	14.1
problem	12.2	*significant*	8.4	*cargo*	13.1	*primary*	11.0	*success*	13.5

3.2. The period 2000-2019

The full texts of the 742 papers from 2000 to 2019 were decomposed into 62,767 text segments. In total, there were 2,039,702 occurrences of content words, of which 61,588 were associated with distinct forms (providing a lexical richness of 2.8%) and 21,811 (approximately 32.4% of the forms) with *hapax legomena* (words with a single occurrence). Overall, 210 words (approximately 0.3% of all distinct forms) represented one-third of the corpus occurrences. The ratio of this small subset of words in the overall corpus is interpreted as an indication of corpus consistency (Mandják et al., 2019; Lavissière et al., 2020). Moreover, the most frequent 1,578 words corresponded to two-thirds of occurrences in the corpus, and 60,010 words corresponded to the remaining third.

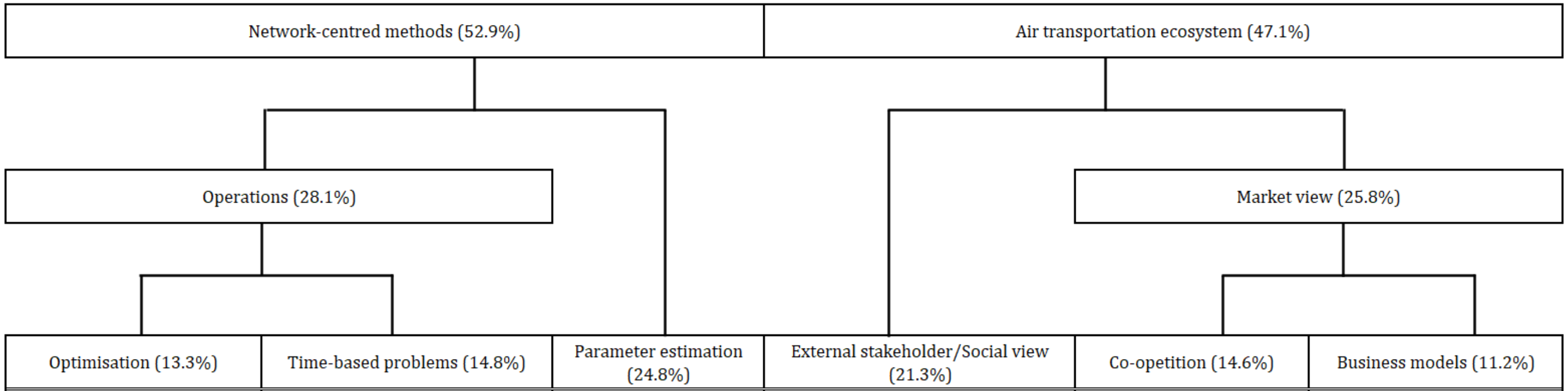
3.2.1. Broad analysis

3.2.1.1. Reinert's method

Reinert's method was applied to the entire collection of text segments. The algorithm classified 57,820 text segments into six identified classes, or 92.1% of the total. Figure 2 depicts how the corpus was branched after the algorithm was applied. The results indicate six specific thematic vocabulary classes, with the corpus' corresponding percentages of text segments.

The classes found were *parameter estimation*, *time-based models*, and *optimisation*, forming a branch of methodologies employed (*"network-centred methods"*), and *co-opetition*, *business models*, and *external stakeholder/social view* forming a branch of applications (*"air transportation ecosystem"*).

Figure 2. Corpus breakdown (2000-2019).



Optimisation (13.3%)

Content words	χ2
constraint	4041.5
solve	3925.6
solution	2917.2
bound	2216.4
problem	1751.0
set	1723.2
objective function	1655.7
optimal solution	1610.6
let	1569.4
iteration	1476.4
denote	1275.7
formulation	1185.8
decision variable	1106.9
arc	1085.5
leg	1029.3
flight leg	1025.7
optimal	995.1
maximize	919.0
algorithm	864.1
proof	845.1

Time-based problems (14.8%)

Content words	χ2
flight	5691.6
delay	5301.4
aircraft	3628.9
schedule	2990.4
time	2463.0
day	2215.1
arrive	1814.9
departure time	1584.0
depart	1526.3
hour	1525.7
arrival time	1319.8
min	1305.0
minute	1254.4
flight delay	1181.4
departure	1054.0
arrival	1052.2
arrival/departure	1000.1
flight time	954.6
flight schedule	929.2
duration	909.4

Parameter estimation (24.8%)

Content words	χ2
data	2163.0
model	2138.9
method	2015.8
propose	1119.7
estimate	1074.5
section	1046.0
base	1026.5
node	927.0
present	866.9
study	823.4
test	812.9
metric	806.0
coefficient	745.2
approach	678.3
analysis	656.4
application	654.4
result	622.6
performance	617.3
estimation	601.7
value	601.5

External stakeholder/Social view (21.3%)

Content words	χ2
country	1832.7
government	1544.2
development	1494.2
region	1355.9
company	1262.8
air transport	1033.7
investment	1009.2
aviation	985.4
infrastructure	981.6
China	969.8
tourism	961.0
national	883.9
industry	863.6
policy	779.4
international	745.4
world	725.3
economic	671.6
social	667.8
political	653.8
city	649.6

Co-opetition (14.6%)

Content words	χ2
market	2599.1
alliance	2246.3
spoke	2021.1
competition	1881.2
hub	1777.0
airline	1667.8
increase	1602.6
connect	1269.1
hub airport	1089.4
HSR	960.2
passenger	940.3
effect	880.5
merger	864.4
route	782.0
frequency	746.0
compete	726.1
global alliance	686.9
decrease	683.6
airfare	666.1
serve	620.6

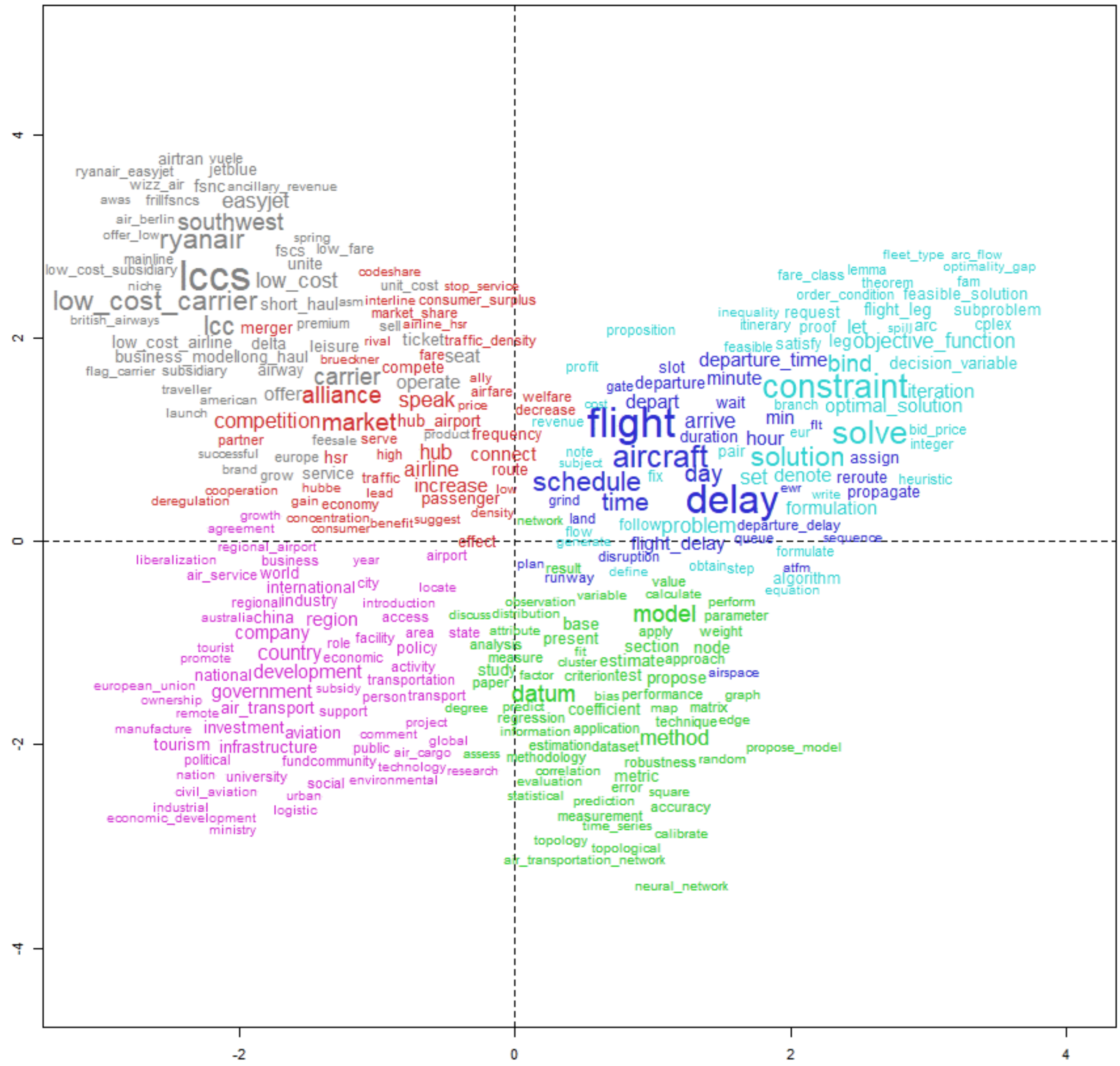
Business models (11.2%)

Content words	χ2
LCCs	5478.4
Ryanair	2990.6
low-cost carrier	2914.2
LCC	2745.5
Southwest	2244.3
carrier	2206.1
easyJet	2118.9
low-cost	2103.1
network carrier	1671.7
offer	1394.3
seat	1364.1
operate	1267.2
FSNC	1157.6
low-cost airline	1142.4
service	1134.4
business model	1047.1
ticket	981.3
short-haul	961.0
secondary airport	955.7
JetBlue	922.2

3.2.1.2. Correspondence analysis

Correspondence analysis was conducted on the results of Reinert's method (Greenacre, 2007). In practice, researchers often adhere to a two-dimensional representation, given the ease of presenting results. Figure 3 depicts the projection into the first two principal axes of the positioning of words from each class in relation to one another.

Figure 3. Correspondence analysis (2000-2019).



By analysing the classes' vocabulary distribution, the primary principal axis (horizontal) can be interpreted as ranging from a qualitative view, using both social and managerial vocabularies, to a discourse related to model representations laden with mathematical terms. This factor essentially replicates the primary division of the corpus into the methodologies/applications branches shown in Figure 2. The secondary principal axis (vertical) is interpreted as ranging from a broad, general vocabulary (with societal implications and more long-term objectives on the left side and broad terms related to methodology on the right side) to a context-specific vocabulary, heavily focused on problem-solving and the individual contexts of specific airlines and their operations.

3.2.1.3. Analysis of topic prevalence in journals

The results of the analysis of the passive variable associated with the journals from the examined corpus are presented (Reinert, 1990). Such an analysis helps the understanding of the total output of each journal, in addition to their profile as related to the identified themes. This result is illustrated in Table 1, where the heat map colour scale ranges from white (corresponding to a frequency of 0% of text segments assigned to a class) to black (100%). For example, the proportion of text segments indicates that *Transportation Science* is focused mainly on methodological themes. However, statistically significant (and positive) χ^2 values (682.3 and 5820.5, respectively) were obtained only for the *time-based problems* and *optimisation* classes.

The editorial lines of *Transport Policy* and the *Journal of Transport Geography* mainly surrounded the *external stakeholder/social view* (231.9, 1,567.5), *business models* (142.2, 244.1), and *co-opetition* (84.2, 87.2) classes. Similar results were obtained for the *Journal of Air Transport Management*, albeit with a different order of thematic priorities, namely, *business models* (938.8), *external stakeholder/social view* (475.4), and *co-opetition* (132.1).

Table 1. Thematic decomposition by journal (2000-2019).

	Proportion of text segments								χ^2 per class					
Journal	**Co-Op**	**BM**	**PE**	**TM**	**Opt**	**Ex St**	**Text segments**	**Main class**	**Co-Op**	**BM**	**PE**	**TM**	**Opt**	**Ex St**
Case Studies on Transport Policy							260	Business models	-6.8	334.3	-19.2	-22.1	-2.2	-4.2
Economics of Transportation							538	Co-opetition	269.7	-14.1	-8.6	-21.9	30.9	-82.4
EURO Journal on Transportation and Logistics							311	Optimisation	-42.1	-29.0	7.6	-8.6	242.1	-17.8
European Journal of Transport and Infrastructure Research							344	External stakeholders	-4.0	2.1	-35.0	0.1	-23.5	115.8
European Transport Research Review							381	External stakeholders	-10.7	15.6	-15.8	-19.0	-59.5	203.2
IEEE Transactions on Intelligent Transportation Systems							744	Time-based problems	-119.1	-79.9	46.4	327.4	16.6	-89.1
International Journal of Sustainable Transportation							150	Parameter estimation	-21.1	-16.8	160.3	-16.7	-15.6	0.4
International Journal of Transportation Science and Technology							61	Co-opetition	6.7	-2.4	2.1	-1.4	-1.2	-0.4
Journal of Advanced Transportation							978	Optimisation	-76.0	-36.0	88.3	0.0	134.5	-61.7
Journal of Air Transport Management							13782	Business models	132.1	938.8	-62.5	-397.7	-1234.6	475.4
Journal of Modern Transportation							103	Parameter estimation	-11.2	-13.0	45.4	8.9	-9.7	-1.4
Journal of Transport Economics and Policy							1054	Co-opetition	357.9	-2.0	-18.1	-1.1	-7.2	-56.4
Journal of Transport Geography							6204	External stakeholders	87.2	244.1	-97.1	-704.6	-991.0	1567.5
Journal of Transport History							339	External stakeholders	-40.8	-13.2	-107.0	-50.2	-59.1	1006.2
Journal of Transportation Engineering							544	Time-based problems	-91.2	-56.4	70.7	557.8	-22.8	-106.5
Journal of Transportation Engineering Part B: Pavements							95	Parameter estimation	-16.2	-12.0	161.8	-10.4	-10.2	-3.3
Proceedings of the Institution of Civil Engineers: Transport							97	External stakeholders	-16.5	-6.4	6.7	-12.7	-16.8	85.5
Research in Transportation Business and Management							863	Business models	-8.3	664.3	-134.1	-30.9	-131.1	87.5
Research in Transportation Economics							642	Business models	52.8	607.3	-147.3	-78.0	-94.3	10.8
Transport							207	Parameter estimation	-26.6	-26.3	67.0	-9.0	-29.3	48.1
Transport and Telecommunication							109	External stakeholders	-12.2	2.1	-28.4	-7.2	-16.6	176.1
Transport Policy							1910	External stakeholders	84.2	142.2	-110.6	-91.6	-235.6	231.9
Transport Reviews							234	External stakeholders	0.5	4.1	-14.3	-20.0	-36.1	114.8
Transportation							341	External stakeholders	-22.3	-34.8	31.4	-15.3	-27.7	110.2
Transportation Journal							268	External stakeholders	6.8	0.3	-31.2	-15.3	-15.2	96.6
Transportation Letters							129	External stakeholders	0.1	-4.4	16.8	-19.9	-22.4	23.3
Transportation Planning and Technology							1124	Time-based problems	-5.6	-48.7	47.3	143.1	-30.4	-25.0
Transportation Research Part A: Policy and Practice							3956	Co-opetition	194.1	1.9	-3.8	0.0	-80.4	-11.0
Transportation Research Part B: Methodological							3151	Optimisation	320.2	-227.0	-90.7	22.8	826.5	-511.3
Transportation Research Part C: Emerging Technologies							3147	Parameter estimation	-485.8	-408.8	663.5	472.4	255.4	-598.6
Transportation Research Part D: Transport and Environment							986	Time-based problems	-26.5	-47.4	6.7	83.0	-3.5	1.1
Transportation Research Part E: Logistics and Transportation Review							6869	Optimisation	-5.6	-330.9	383.5	53.5	458.0	-852.0
Transportation Research Part F: Traffic Psychology and Behaviour							151	External stakeholders	-25.8	-19.1	27.1	-13.2	-19.6	82.8
Transportation Research Record							2705	External stakeholders	-52.4	0.5	0.0	78.6	-188.7	107.2
Transportation Science							4414	Optimisation	-610.6	-523.8	-233.6	682.3	5820.5	-1071.3
Transportmetrica							243	Optimisation	-5.1	-26.5	23.9	-6.4	114.8	-41.1
Transportmetrica A: Transport Science							341	Parameter estimation	-4.4	-30.8	278.1	-10.7	-26.1	-18.9
Transportmetrica B: Transport Dynamics							45	Parameter estimation	-7.7	-5.7	79.8	-0.2	-5.6	-7.7

3.2.1.4. Correlation between methodologies and applications

A Jaccard similarity coefficient was employed to quantify the co-occurrence of methodologies and applications in the 2000-2019 corpus. The coefficient consists of the ratio of the number of articles in which a particular methodology and application appear together (intersection) to the number of articles in which at least one appears (union). An article was considered to include a given theme if the χ^2 value of their association was no less than 3.84, corresponding to $p < 0.05$ for a χ^2 distribution with one degree of freedom.

Table 2 depicts the results. The highest co-occurrences of themes are between *co-opetition* and *optimisation* and between *external stakeholder/social view* and *parameter estimation*. Overall, the results suggest that studies on *co-opetition* have been more clearly associated with the application of the methodological themes found in the analysis, all of which are quantitative. This finding can be contrasted with studies on *business models*, which have shown less association with any of these themes, suggesting a more descriptive approach.

Table 2. Thematic correlations (2000-2019).

Theoretical motivations \ Methodologies	Optimisation	Time-based models	Parameter estimation
Business models	0.00	0.01	0.02
Co-opetition	0.11	0.02	0.03
External stakeholders/social view	0.01	0.01	0.07

3.2.1.5. Temporal trends in thematic discussions

Table 3 illustrates the temporal trends of discourse prominence for each of the six identified classes. As in the previous subsection, an article was considered to include a given theme if the χ^2 value of their association was no less than 3.84. The predominance of a theme in each period (in %) is indicated by the ratio of the number of articles containing that theme to the total output of each period. The class *parameter estimation* is highlighted as the only one that consistently increased its share of discussions in the literature, growing from 6.5% to 35.5% of discussions. A possible explanation is an increase in the average number of words per paper manifested over the two decades. While the average number of words was 6,198 in the period from 2000 to 2004, this number rose to 8,195 from 2015 to 2019, an increase of 32%, suggesting that papers in the latter period provided more details for the methodologies employed.

The decrease in prominence of the *external stakeholder/social view* class in the second five-year period is noted. However, this theme gained and maintained some prominence in the following years. In addition, the *time-based models* class showed steady growth until 2014 and then decreased in 2015–2019.

Table 3. Thematic and temporal trends (2000-2019).

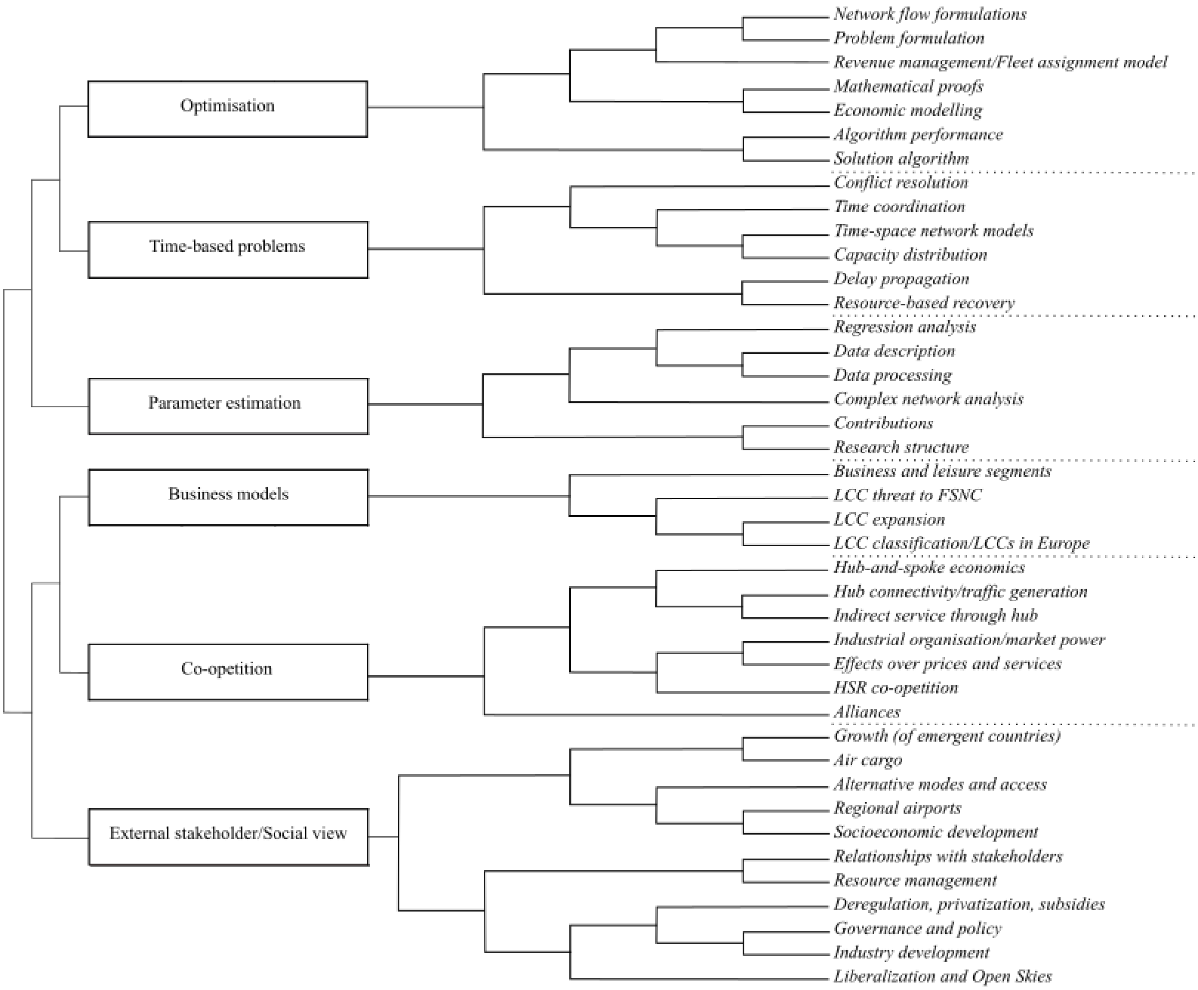
Period	2000-2004	2005-2009	2010-2014	2015-2019	Trend
Co-opetition	37.7%	33.9%	27.1%	21.0%	
Business models	23.4%	26.1%	23.1%	16.7%	
External stakeholders/social view	35.1%	23.5%	27.1%	27.5%	
Parameter estimation	6.5%	20.0%	25.3%	35.5%	
Optimisation	33.8%	23.5%	24.0%	18.5%	
Time-based models	15.6%	16.5%	22.2%	20.4%	

3.2.2. Detailed analysis

In the following discussions, a detailed breakdown of the corpus resulting from a specification of 100 terminal classes is used, which resulted in 50 stable classes. The goodness of fit for the detailed analysis was inferior to that of the original (broad) analysis, with only 81.7% (51,257) of text segments being classified. Furthermore, it was inferior to the overall (summed) goodness of fit from the advanced analyses of the six classes. However, such a comparison is bound to be unfavourable to the detailed analysis since only 27 classes (approximately half) were produced by the alternative. Based on the resulting tree diagram of the detailed analysis, it was possible to identify the branches that best corresponded to the original six classes.

The underlying subtopics of each class were identified by cross-checking the words resulting from the detailed analysis with those produced by the original analysis. For convenience, the class breakdowns are collectively depicted in Figure 4.

Figure 4. Breakdown of the initial classes (2000-2019).



3.2.2.1. Air transportation ecosystem

Concerning the *co-opetition* class, the detailed analysis produced seven topics recognised as associated with it (Figure 4). These subclasses revolved around the hub-and-spoke network configuration and its economics; issues related to market structure, such as the entry of newcomers, mergers, and market power; issues related to cooperation, such as alliances and codeshare agreements between airlines; and the social welfare considerations of high-speed rail (HSR) competition/cooperation. Apart from HSR, it is noteworthy how such topics were featured more prominently from 1973 to 1999 (Figure 1).

The detailed analysis of the *business models* class produced four subclasses (Figure 4). The themes emerging from this class included the expansion of LCCs, particularly in Europe and Asia; the dichotomy between business and leisure travellers; the LCC threat to full-service network carriers (FSNCs) (with a particular focus on the "*Southwest effect*", most clearly discerned from the significant text segments of this subclass rather than from vocabulary alone); and efforts to classify LCC business models, particularly for airlines in Europe.

Finally, the detailed analysis produced eleven subtopics associated with the *external stakeholder/social view* class (Figure 4). Here, subclasses addressed the government role in air transport, such as investments, governance, and policy formulations; efforts related to deregulation, privatisation, and subsidies; and considerations of liberalisation and Open Skies agreements (particularly for Europe). Other issues included developments of the air transport industry, such as environmental impacts and globalisation; how it influences (and is influenced by) the growth of emergent countries and socioeconomic development overall; the role of air cargo in such developments; issues of the accessibility of remote communities and the integration of air transport with alternative modes; and the way airlines interact with customers, employees, and other companies in their supply chain.

3.2.2.2. Network-centred methods

The detailed analysis produced twelve subtopics for the parameter estimation class, six of which are presented in Figure 4, as the other six classes were either outliers or had a much-reduced vocabulary. Four of these reduced or outlier classes, namely, *decision-making*, *real-time monitoring*, *dynamic interactions,* and *(network) data envelopment analysis (DEA),* were related to outlier papers (the last of these due to the name of the methodology—*network* DEA—and the context of its application being air transport). A residual class somewhat associated with *hub location* had text segments strongly tied to model proposals and, hence, research contributions, which explains its appearance in the *parameter estimation* class rather than in the *optimisation* class. Finally, a class associated with the topic *predictions and statistical descriptions* was a residual class that was not distinctly different from the *data description* and *data processing* classes. The remaining themes in this class range from general discussions of research contributions and vocabulary pertaining to research structure (e.g., *section*, *organise*, *discuss*, *present*, *literature review*), data description, and data processing to more specific vocabulary related to particular methods employed, namely, complex network analysis (together with graph theory) and regression analysis.

Complex network analysis, regression analysis, and data description/processing are arguably the most common methods employed to analyse networks apart from optimisation. The third of these has some vocabulary that reflects comparative analysis, statistical descriptions, and summarisation indexes. The residual subclasses here are not surprising, as text segments related to contributions and research structure are ubiquitous across all papers and may play a role in producing subclasses that lack a cohesive theme.

For the *time-based problems* class, the detailed analysis produced six subclasses (Figure 4). The major themes emerging from these subclasses included the issues of conflict resolution and aircraft separation; time coordination between arriving and departing flights; congestion, queues, and capacity distribution over a day; time-space network models; and disruptions, especially on delays and strategies for recovery of operations.

Finally, the detailed analysis produced seven subtopics for the *optimisation* class (Figure 4). The themes comprehended concepts such as economic models, particularly those of profit or social welfare maximisation, together with their mathematical proofs; vocabulary related to the steps of problem formulation, solution algorithms and algorithm performance; and more specific applications, particularly problems of revenue management and fleet assignment or those formulated as network flow.

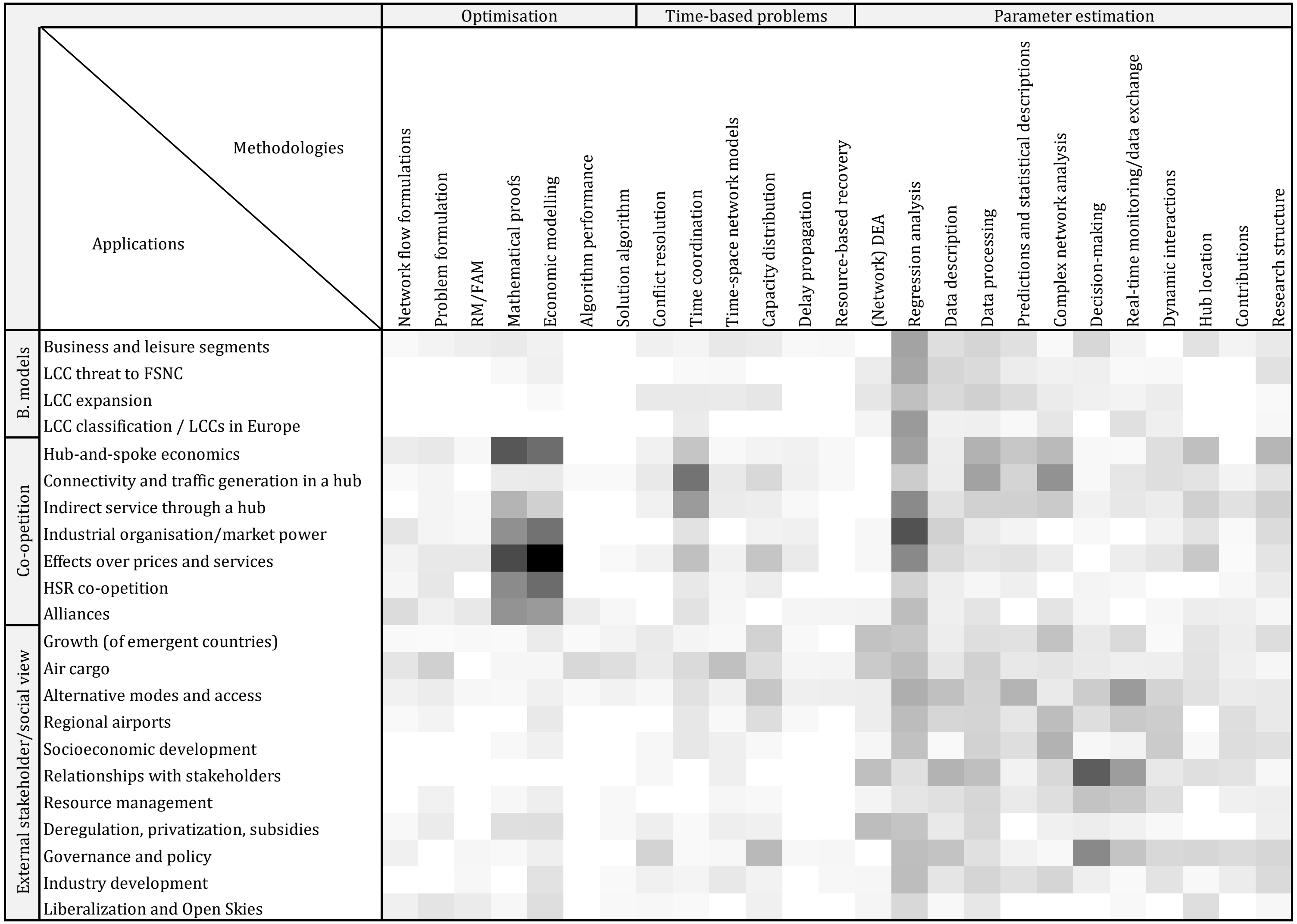
3.2.2.3. Correlation between methodologies and applications

Table 4 depicts the results of the same procedure described in subsection 3.2.1.4 when applied to the subclasses found in the detailed analysis. Highlights include the correlations of the vocabularies of *mathematical proofs* and *economic modelling* with *hub-and-spoke economics*, *market power*, *price effects*, *HSR co-opetition*, and *alliances*. *Regression analysis* stands out because it is correlated with a wide range of applications, particularly themes on *business models* and *co-opetition*. At the same time, *complex network analysis* appears more frequently in discussions related to the *hub-and-spoke system* (see also the methodological subclass *time coordination*), *regional airports*, and *socioeconomic development*.

The associations of the *business model* and *external stakeholder/social view* themes with discussions of *optimisation* and *time-based models* are seemingly underrepresented, indicating possible avenues for future research. In particular, the use of *mathematical proofs* and *economic modelling*, methodologies strongly tied to *co-opetition*, appears to offer the most promising alternative, as applications could be generalised similarly to *regression analysis*.

Complex network analysis associated with discussions of *business models* is yet another underrepresented approach.

Table 4. Subtheme correlations (2000-2019).



3.2.2.4. Temporal trends in thematic discussions

Table 5 presents the results from the same procedure described in subsection 3.2.1.5 when applied to the subclasses found in the detailed analysis, focusing only on applications. The subclass *alliances* is highlighted, showing a noticeable decrease in prominence from 2010 to 2019. Such a concentration of discussions in the period 2000–2009 can be explained by the time of occurrence of all the latest prominent mergers in the US that took place between 2001 and 2009. The *liberalisation and Open Skies* and *deregulation, privatisation, and subsidies* classes also experienced substantial decreases in the last decade, presumably due to most countries in the free world already having undergone such developments. In contrast, the *LCC classification/LCCs in Europe* and *regional airports* classes showed an overall increase in discussion throughout the period. Finally, the increase in discussions surrounding *HSR co-opetition* is noted. This increase can be traced to the increasing adoption of alternative means of transport by a growing number of countries to reduce the environmental impacts of air transport (among other modes).

Table 5. Subtheme temporal trends (2000-2019).

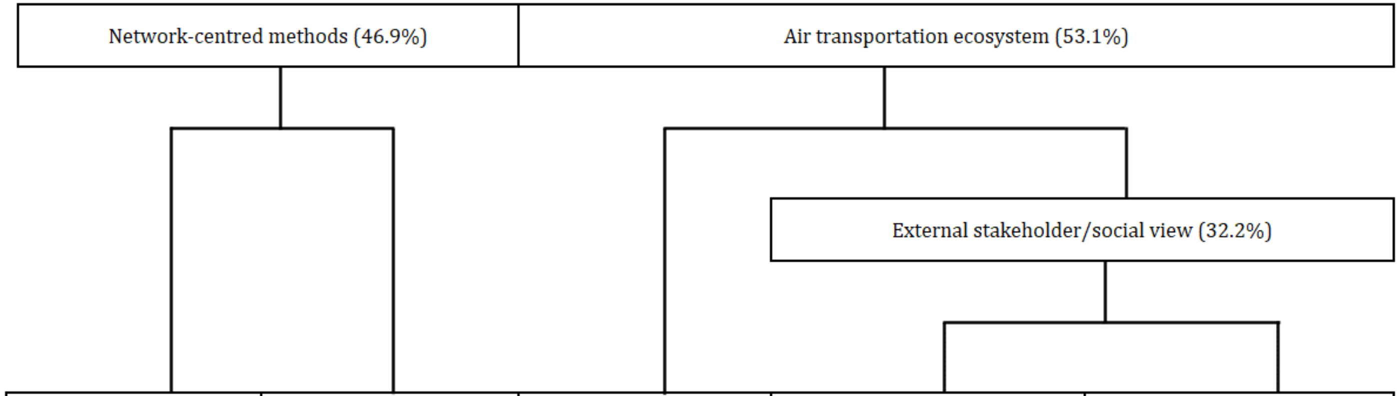
Period	2000-2004	2005-2009	2010-2014	2015-2019	Trend
Business and leisure segments	9.1%	18.3%	13.3%	7.7%	
LCC threat to FSNC	11.7%	17.4%	8.4%	9.0%	
LCC expansion	13.0%	13.9%	13.3%	10.8%	
LCC classification / LCCs in Europe	3.9%	7.8%	8.0%	8.0%	
Hub-and-spoke economics	18.2%	17.4%	16.4%	6.2%	
Connectivity and traffic generation in a hub	10.4%	11.3%	13.8%	11.4%	
Indirect service through a hub	20.8%	16.5%	13.8%	9.6%	
Industrial organisation/market power	16.9%	13.9%	14.7%	8.0%	
Effects over prices and services	9.1%	17.4%	16.9%	9.3%	
HSR co-opetition	0.0%	2.6%	6.7%	7.1%	
Alliances	10.4%	12.2%	3.6%	5.9%	
Growth (of emergent countries)	13.0%	6.1%	14.7%	13.3%	
Air cargo	14.3%	5.2%	6.7%	4.9%	
Alternative modes and access	11.7%	7.0%	12.0%	10.5%	
Regional airports	10.4%	5.2%	10.7%	13.3%	
Socioeconomic development	10.4%	3.5%	11.6%	11.4%	
Relationships with stakeholders	5.2%	9.6%	8.4%	10.8%	
Resource management	11.7%	10.4%	8.4%	6.2%	
Deregulation, privatization, subsidies	11.7%	8.7%	11.6%	6.5%	
Governance and policy	15.6%	7.0%	10.7%	7.4%	
Industry development	15.6%	13.0%	11.6%	9.3%	
Liberalization and Open Skies	16.9%	8.7%	10.7%	5.2%	

3.3. The period 2020-2021

The 2020-2021 period is noteworthy due to the significant impacts the air transport sector faced due to the COVID-19 pandemic and the resulting publications aimed at addressing such issues. An initial analysis of the full period 2000-2021 was sought. However, results were mostly unchanged from those obtained for the 20 years 2000-2019. An explanation for this outcome is that discussions related to the last two years, still in an emerging stage, were overshadowed by established discussions and terminologies developed before or during 2000-2019, given the statistical approach adopted. Issues that have not been properly established likely will not have reached a consensus of terminology yet, thus not obtaining high enough numbers to stand out in a statistical treatment. Given these results, a separate analysis was done to provide insights into the discussions from 2020 to 2021. A total of 177 papers were decomposed into 21,495 text segments, 19,359 of which (90.1%) were classified into five classes, as depicted in Figure 5. Three of these classes presented only minor changes when compared with 2000-2019 results, namely: *market view*, uniting vocabulary from both *business models* and *co-opetition* classes (20.9%), *operations*, uniting vocabulary from *optimisation* and *time-based problems* (25.4%), and *parameter estimation* (21.4%). However, it is noted that *operations* has been more strongly related to time-based problems in the 2020-2021 period.

Still, the two remaining classes, *connectivity and accessibility* (15.6%) and *COVID-19 pandemic* (16.6%), presented more distinct themes, to some extent, reminiscent of vocabulary from the class *external stakeholder/social view*. A view on thematic prevalence indicates that the *Journal of Transport Geography*, *Research in Transportation Business and Management*, and the *Journal of Air Transport Management* were the journals where *COVID-19 pandemic* discussions were more significant (χ^2 values of 263.8, 103.1, and 57.1, respectively).

Figure 5. Corpus breakdown (2020-2021).



Operations (25.4%)		Parameter estimation (21.5%)		Market view (20.9%)		Connectivity and accessibility (15.6%)		COVID-19 pandemic (16.6%)	
Content words	χ2	Content words	χ2	Content words	χ2	Content words	χ2	Content words	χ2
flight	1961.4	*method*	1304.5	*market*	1246.7	*city*	1198.3	*COVID-19*	648.8
aircraft	1285.0	*model*	1086.8	*price*	1197.4	*airport*	781.6	*country*	475.3
delay	1212.4	*data*	1080.6	*airline*	974.4	*region*	512.2	*economic*	457.4
schedule	867.9	*input*	763.5	*fare*	786.2	*China*	510.2	*development*	451.5
time	827.0	*learn*	743.7	*carrier*	759.8	*country*	441.5	*crisis*	442.4
assign	807.2	*prediction*	711.3	*competition*	718.4	*Beijing*	435.3	*research*	405.1
day	664.8	*predict*	696.5	*LCCs*	596.2	*connectivity*	401.9	*government*	391.9
constraint	474.3	*algorithm*	546.8	*HSR*	586.0	*Shanghai*	356.4	*industry*	382.9
min	462.0	*test*	465.9	*LCC*	562.8	*international airport*	349.0	*aviation*	360.3
departure time	407.0	*output*	441.7	*profit*	557.4	*Guangzhou*	346.9	*air transport*	356.1
departure	400.5	*neural network*	415.1	*offer*	534.7	*destination*	333.7	*study*	327.9
trajectory	395.7	*technique*	401.0	*welfare*	534.6	*locate*	311.0	*pandemic*	305.3
airspace	377.6	*propose*	387.0	*route*	475.6	*accessibility*	294.5	*spread*	300.4
arrival	376.6	*value*	384.1	*fee*	454.6	*Nuuk*	270.0	*investment*	288.9
arrive	370.2	*accuracy*	357.0	*HSR operator*	441.7	*island*	267.7	*social*	287.1
minute	344.9	*approach*	337.0	*spoke*	440.9	*rail*	266.4	*COVID-19 pandemic*	260.1
arrival time	306.7	*predictor*	328.2	*airfare*	410.7	*decline*	257.6	*role*	259.4
cost	286.6	*sample*	326.8	*business model*	402.1	*Ilulissat*	256.3	*policy*	256.8
cancellation	263.2	*variable*	315.4	*passenger*	373.7	*international*	238.4	*air transportation*	250.1
gate	257.3	*dataset*	305.4	*long-haul*	371.8	*population*	223.5	*transportation*	247.6

A closer look into idiomatic expressions included in the class *COVID-19* reveals the concepts of *COVID-19 pandemic*, *crisis communication*, *economic development* (also *growth*, *activity*, *impact*), *transportation* (also *aviation*) *network*, and *international aviation* (*also connectivity*) as being particularly significant. Similarly, for class *connectivity and accessibility*, the expressions *international airport* (also *flight*), *direct flight* (also *complete entry*) *suspension*, *entry restriction*, *air connectivity*, *network efficiency* (also *connectivity*), and *direct* (also *flight*) *connection* are noted.

4. Discussion and conclusions

The results suggest that, in the period 2000-2019, topics on airline operational network decisions, such as air transport network development, network configurations, and destination selection, were underrepresented, giving space to broader perspectives on how air transport networks are investigated, with many topics that one might not readily attach to them being considered. Contrast these results with those provided by the analysis of 1973-1999, presenting a much narrower perspective, geographically inclined towards Europe and the US. Similar results to the period 2000-2019 are found for 2020-2021, although discourse has been heavily weighted towards COVID-19, as would be expected, with vocabulary surrounding the topic appearing in 1/6th of discussions.

Additionally, this research establishes the main applications and methodologies employed in the literature by correlating their usage from 2000 to 2019. As the primary approaches adopted in the literature, the prominence of linear programming and economic models used in optimisation are recognised, with regression analysis, complex network analysis, comparative analysis, statistical descriptions, and summarisation indexes being used in more general applications. Key areas identified as needing further attention by scholars relate to underrepresented or undeveloped uses of methodologies in particular applications. The theme *business models* still offers further investigation opportunities through quantitative approaches. *Regression analysis* appears to be a ubiquitous approach across all applications. In contrast, *complex network analysis* and *economic modelling* are the most promising alternatives for future research on the *business models* and *external stakeholder/social view* classes. Concerning the temporal evolution of discussions, the *parameter estimation* class has increased prominence. A closer examination of the application subclasses also suggests increasing or ongoing discussions of *LCC classification/LCCs in Europe*, *regional airports*, and *HSR co-opetition*.

Like other studies, this research has limitations. While efficient at identifying prominent themes, Reinert's method, owing to its statistical nature, omits marginal discussions, which could be valuable for understanding emerging (or neglected) themes. A recent example is the discussion of the role COVID-19 played on the emergence of new types of networks (Klophaus et al., 2021). Moreover, spaCy's pre-trained convolutional neural network (CNN), used for POS tagging, comprises a predictive model and is thus prone to errors in judgement for some of its assigned labels (its accuracy for part-of-speech tags is evaluated at 97.06%). Finally, the attention to transport-related journals, while guaranteeing a more cohesive selection of papers and thus reducing the number of outliers, may have excluded some interesting nuances on how the topic may be depicted in more varied fields of enquiry. Further developments in future studies could focus on the particular themes and subthemes identified (e.g., *alliances* or *regional airports*) and provide a more direct analysis of the results, made possible by more manageable database sizes.

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