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RAILWAY INFRASTRUCTURE PROJECT DELAYS: A BIBLIOMETRIC ANALYSIS AND UNIFIED CLASSIFICATION OF CONTRIBUTING FACTORS

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A b s t r a c t

Timely completion of railway projects is affected by numerous interacting organisational, technical, contractual and administrative factors. This study identifies and systematises the main causes of delay through a bibliometric analysis of 32 publications selected from Scopus and a critical review of 41 sources, including additional academic sources identified outside the Scopus dataset and four reports of the Polish Supreme Audit Office (NIK). A total of 683 factor entries were extracted and, after terminological harmonisation, consolidated into 552 unique harmonised factors grouped into 12 categories. The categories containing the largest numbers of unique harmonised factors concerned project organisation and management, contractor performance, administrative decisions and approvals, and design documentation. Railway-specific factors, particularly track possessions and access to operational infrastructure, formed a relatively small category within the developed classification. The proposed classification provides a basis for comparing previous findings and for further empirical research on railway project delays.

Keywords: railway projects, delays, risk factors, literature review, bibliometric analysis

1. INTRODUCTION

Timely completion of railway projects is one of the fundamental conditions for achieving the intended technical, economic and social outcomes. Extending the implementation period increases project costs, delays the commissioning of infrastructure and limits the possibility of achieving the planned transport effects [15], [39]. In the case of investments co-financed from public funds, delays may additionally affect the timely use of available financial resources and the implementation of planned investment programmes. Railway projects are among the most complex infrastructure projects. They involve the simultaneous execution of works in multiple disciplines, works carried out on operational railway

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infrastructure, and the need to obtain numerous administrative decisions and approvals. The completion time is affected by technical and organisational conditions as well as formal and legal, environmental and contractual issues. In practice, delays are most often not the result of a single event, but of the coexistence of many interrelated factors [15], [39], [42], [53]. The issue of timely project completion has been the subject of scientific research for many years. Previous studies have examined delay factors in different project settings. Goodier et al. [15] investigated international EPC high-speed rail construction projects, while Mittal and Paul [42] focused on metro rail projects in India. Leśniak and Piskorz [32] examined factors delaying construction projects delivered under the Design and Build system. These studies provide context-specific findings that require harmonisation before they can be compared within a common classification. However, the vast majority of studies concern construction investments in general, while publications devoted exclusively to railway projects are considerably less numerous. They most often focus on selected countries, individual projects or specific project delivery models, such as EPC or Design and Build [7], [15], [22]. An additional problem is the lack of a uniform approach to classifying factors affecting the timely completion of railway projects. Individual authors use different terminology and different levels of detail, which makes it difficult to compare research results and synthesise the existing state of knowledge. The literature analysis also indicates that studies based on surveys, expert interviews and case studies predominate. Data derived from the actual performance of contracts are used much less frequently, while in the Polish literature there are practically no studies based on a systematic analysis of contract documentation from railway projects.

The aim of this article is to identify, systematise and classify the factors affecting the timely completion of railway projects on the basis of Polish and international scientific literature. The research included a bibliometric analysis and a critical literature review, followed by the extraction and standardisation of the identified factors and their assignment to 12 thematic categories. The developed classification systematises the existing state of knowledge and provides a basis for further research on the mechanisms leading to delays and methods for identifying risks to the timely completion of railway projects.

The contribution of this study lies in bringing factors reported in separate Polish and international sources into a common analytical structure. Rather than proposing a new ranking of delay causes, the study links source-specific factor entries to harmonised factor names and assigns them to a shared set of categories. This provides a consistent basis for comparing findings across studies that use different terminology and levels of detail.

2. RESEARCH METHODOLOGY

The research methodology comprised four stages: searching for and selecting publications, bibliometric analysis, critical literature review, and synthesis of the results. The adopted approach combines a quantitative analysis of scientific output with a qualitative analysis of publication content. The bibliometric analysis and the critical literature review were based on partially overlapping sets of sources and served different research purposes. The research procedure is presented in Fig. 1.

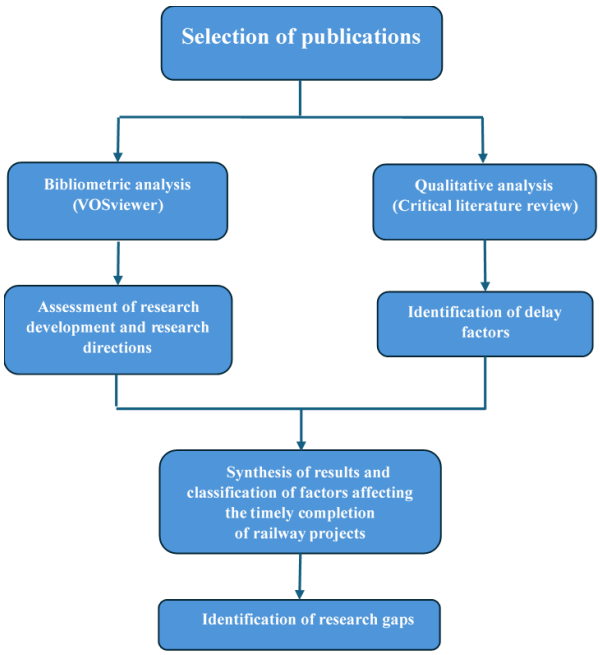

Fig. 1. Research procedure

The bibliometric analysis used a single dataset exported from Scopus. Scopus was selected as the single data source in order to ensure a consistent metadata structure (author names, affiliations and keywords) and a uniform citation basis, which are essential for co-occurrence and citation-based network analysis. Merging records from several databases would have required deduplication and harmonisation of records, introducing an additional source of error. This choice was also compatible with VOSviewer, which processes exports from one database at a time. Although Web of Science indexes some engineering journals not covered by Scopus [44], the overlap between the two databases in engineering is high at the document level, with Scopus capturing approximately 94% of the citations found in Web of Science [41]. Single-database designs combining Scopus with VOSviewer are also well established in bibliometric studies in civil engineering and construction [18], [62]. Consequently, the results of the bibliometric analysis characterise the publications selected from that database and are not presented as an exhaustive account of research on railway project delays. The critical review served a separate purpose and was therefore supplemented with relevant sources identified outside the Scopus dataset. This supplementation broadened the evidence used for factor identification but did not extend the coverage of the bibliometric analysis. Due to the limited number of publications concerning factors affecting the timely completion of railway projects, the critical literature review was supplemented with relevant sources. Scientific publications were identified through Google Scholar using Polish and English keywords related to project delays, timely completion and railway projects, as well as through the reference lists of publications concerning project delays. Doctoral dissertations and a scientific monograph directly related to the scope of the study were also included. Reports of the Supreme Audit Office concerning the implementation of railway projects in Poland were also included in the critical literature review. Four reports were selected because they contained findings concerning delays and factors affecting the timely completion of railway projects. These reports were not included in the bibliometric analysis. The search strategy for the Scopus database was developed on the basis of terminology used in the literature on railway projects, project management and project delays. The

search was conducted in the TITLE–ABS–KEY[2] fields using the logical operators AND and OR. The Scopus search was restricted to English-language journal articles (document type "Article", source type "Journal") published between 2000 and 2026 in the subject areas of Engineering; Business, Management and Accounting; and Decision Sciences, and concerning railway projects and factors affecting their completion time. The detailed search strategy is presented in Table 1.

Table 1. Search strategy applied to the Scopus database

Concept group	Search objective	Keywords used
Subject of study	Identification of publications concerning railway projects	railway construction project, railway infrastructure project, rail infrastructure project, railway project, rail transportation project, metro rail project, high-speed railway project
Research problem	Identification of publications concerning timely project completion	delay, project delay, schedule, scheduling, time overrun, project duration, completion time

The Scopus search was conducted on 15 July 2026 using the search strategy presented in Table 1 and returned 42 records. The retrieved records were screened on the basis of their titles and abstracts. Ten records were excluded because their main research focus was not related to project implementation, timely completion, schedule delays or factors affecting project duration. The remaining 32 publications were included in the bibliometric analysis performed using VOSviewer.

The critical literature review was based on a partially overlapping set of sources. The abstracts of the 32 publications included in the bibliometric analysis were reviewed with regard to their relevance to the identification of factors affecting the timely completion of railway projects. Based on this assessment, 14 publications were included in the critical literature review. The remaining 18 publications were retained in the bibliometric dataset but were not included in the critical review because they did not meet its relevance criteria. The review was supplemented with sources identified through Google Scholar using Polish and English keywords related to project delays, timely completion and railway projects. Relevant publications identified in the reference lists of studies concerning project delays were also included. In addition, doctoral dissertations and a scientific monograph directly related to the scope of the study were included. This procedure resulted in 23 additional sources not included in the Scopus dataset.

The critical review was additionally supplemented with four reports of the Polish Supreme Audit Office (NIK). The four NIK reports were selected for their relevance to railway project implementation and their documented findings on delays and associated organisational, administrative, technical and contractual problems. They cover PKP PLK infrastructure investments [45], the Railway Station Investment Programme [46], ERTMS/ETCS implementation [47] and the modernisation of selected railway lines [48]. Their inclusion was based on thematic relevance rather than a requirement for evenly spaced publication years. The reports were used as complementary institutional evidence for factor identification, not as a continuous time series or an exhaustive review of NIK audit publications. The final critical literature review comprised 41 sources: 33 scientific publications, three doctoral dissertations, one scientific monograph and four NIK reports.

[2] TITLE-ABS-KEY (("railway construction project*" OR "railway infrastructure project*" OR "rail infrastructure project*" OR "railway project*" OR "rail transportation project*" OR "metro rail project*" OR "high-speed railway project*") AND (delay* OR "project delay" OR "schedule" OR scheduling OR "time overrun" OR "project duration" OR "completion time")) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "DECI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND PUBYEAR > 1999 AND PUBYEAR < 2027

Sources were considered eligible for the critical review if they addressed delays, project duration or risks affecting the implementation of railway construction projects, or provided methodological or contextual information relevant to interpreting these issues. The supplementary search also included Polish studies of construction projects more generally, including bridge projects, where they examined organisational, contractual, administrative or technical causes of delay relevant to the comparison undertaken in this study. Consequently, the critical review was not restricted to railway-specific studies.

Sources focused exclusively on railway operations, transport demand or technical performance without a connection to project implementation or completion time were excluded. Studies concerned with scheduling or optimisation were not automatically included in the critical review: their inclusion depended on their relevance to the interpretation of delay factors or the methodological context of the study.

Inclusion in the critical review did not necessarily imply inclusion in factor extraction. Sources used only for contextual or methodological purposes, or whose relevant findings overlapped with material already represented in the factor database, were not treated as additional independent sources of factor entries. The analytical role of each source is indicated in Table 3.

Table 2. Source selection and analysis procedure

Stage	Scope of activities	Result
I	Searching for publications in Scopus (15 July 2026)	Initial Scopus dataset (n = 42)
II	Screening of titles and abstracts	10 records excluded
III	Final selection for bibliometric analysis	Scopus dataset for bibliometric analysis (n = 32)
IV	Screening of abstracts for the critical literature review	Scopus publications included in the critical review (n = 14)
V	Supplementation with sources identified through Google Scholar, reference lists and additional relevant academic sources	Additional sources included in the critical review (n = 23)
VI	Inclusion of NIK reports concerning railway infrastructure investments in Poland	NIK reports (n = 4)
VII	Final selection for the critical literature review	Critical review dataset (n = 41)
VIII	Identification and extraction of delay factors	Factor database (n = 685 entries)
IX	Exclusion of entries not representing causes of delays	Factor database included in further analysis (n = 683 entries)
X	Terminology harmonisation	Set of unique harmonised factors (n = 552)
XI	Classification	12 categories
XII	Synthesis	Literature review results

The final dataset for the bibliometric analysis comprised 32 publications, while the critical literature review covered 41 sources. The two datasets partially overlapped: 14 of the 32 publications included in the bibliometric analysis were also included in the critical literature review. Consequently, 59 unique sources were included in at least one stage of the study. The sources included in each dataset and their use in the factor extraction process are presented in Table 3.

Table 3. Sources included in the bibliometric analysis and critical literature review

Number	Source	Scopus dataset (n = 32)	Critical review (n = 41)	Factor extraction
1	Aishwarya et al. (2019) [1]	✓	-	-
2	Anysz (2012) [2]	-	✓	✓
3	Anysz and Zbiciak (2013) [3]	-	✓	✓
4	Anysz and Buczkowski (2019) [4]	-	✓	-
5	Behnam et al. (2016) [5]	✓	-	-
6	Bensalah et al. (2019) [6]	✓	-	-
7	Bouraima et al. (2026) [7]	✓	✓	✓
8	Dziadosz et al. (2025) [8]	-	✓	✓
9	Faustini (2026) [9]	✓	-	-
10	Flyvbjerg (2011) [10]	-	✓	-
11	Gao et al. (2025) [11]	✓	-	-
12	Gashaw and Jilcha (2022) [12]	✓	✓	-
13	Gashaw and Jilcha (2023) [13]	✓	✓	-
14	Gheewala et al. (2025) [14]	✓	-	-
15	Goodier et al. (2018) [15]	-	✓	✓
16	Gopang et al. (2020) [16]	✓	✓	✓
17	Güden and Süral (2014) [17]	✓	-	-
18	Ichsan et al. (2025) [19]	✓	-	-
19	Janowiec (2021) [20]	-	✓	✓
20	Kang et al. (2013) [21]	✓	-	-
21	Karim et al. (2024) [22]	✓	✓	✓
22	Kasravi et al. (2019) [23]	✓	-	-
23	Kidd et al. (2019) [24]	✓	-	-
24	King et al. (2023) [25]	✓	-	-
25	Kowalski and Połoński (2018) [26]	-	✓	✓
26	Kowalski et al. (2019) [27]	-	✓	✓
27	Kowalski (2020) [28]	-	✓	-
28	Kuol et al. (2024) [29]	✓	-	-
29	Leśniak and Plebankiewicz (2010) [30]	-	✓	✓
30	Leśniak and Piskorz (2017) [31]	-	✓	✓
31	Leśniak and Piskorz (2018) [32]	-	✓	✓
32	Leśniak and Janowiec (2019) [33]	-	✓	✓
33	Leśniak and Piskorz (2019) [34]	-	✓	-
34	Leśniak (2025) [35]	-	✓	✓
35	Li et al. (2015) [36]	✓	-	-
36	Li and Roberti (2017) [37]	✓	-	-
37	Liao et al. (2025) [38]	✓	-	-
38	Love et al. (2017) [39]	-	✓	✓
39	Macherla and Vilventhan (2025) [40]	✓	✓	-

40	Mittal and Paul (2018) [42]	-	✓	✓
41	Mittal et al. (2019) [43]	✓	✓	-
42	Najwyższa Izba Kontroli (2013) [45]	-	✓	✓
43	Najwyższa Izba Kontroli (2022) [46]	-	✓	✓
44	Najwyższa Izba Kontroli (2023) [47]	-	✓	✓
45	Najwyższa Izba Kontroli (2026) [48]	-	✓	✓
46	Ng and Loosemore (2007) [49]	✓	✓	-
47	Nguyen et al. (2024) [50]	✓	✓	✓
48	Nikjow et al. (2021) [51]	-	✓	✓
49	Piskorz (2023) [52]	-	✓	✓
50	Połoński and Kowalski (2017) [53]	-	✓	✓
51	Połoński et al. (2019) [54]	-	✓	✓
52	Ren et al. (2025) [55]	✓	✓	✓
53	Singh et al. (2022) [56]	✓	✓	✓
54	Steininger et al. (2021) [57]	✓	✓	✓
55	Tang et al. (2014) [58]	✓	-	-
56	Tavassolirizi et al. (2022) [59]	✓	✓	✓
57	Tran et al. (2020) [60]	✓	✓	✓
58	Welde and Bukkestein (2022) [61]	-	✓	-
59	Zhao et al. (2026) [63]	✓	-	-

As shown in Table 3, the datasets used for the bibliometric analysis and the critical literature review partially overlapped. Of the 32 publications included in the bibliometric analysis, 14 were also included in the critical review. In total, 59 unique sources were used in at least one stage of the study. Of the 41 sources included in the critical review, 31 were used for the direct identification and extraction of factors affecting the timely completion of railway projects.

The bibliometric analysis was performed using VOSviewer version 1.6.21 and was restricted to the 32 publications selected from the Scopus database. It included an assessment of research development dynamics and keyword co-occurrence analysis. The co-occurrence analysis was conducted for all keywords using the full counting method. A minimum occurrence threshold of two was applied. Following terminology harmonisation and the exclusion of terms specified in the thesaurus file, 221 distinct keywords remained. Of these, 18 occurred in at least two publications and were included in the co-occurrence analysis. A thesaurus file was used to harmonise synonymous and variant terms and to exclude general terms not directly related to the scope of the analysis. The number of publications, keyword occurrences, total link strength and the structure of clusters generated by the software were used to interpret the results.

For the purpose of the summary analysis, each publication was assigned to one dominant research method. Where a study employed more than one research method, all methods were identified during data extraction, while the method that played the primary role in achieving the main research objective and obtaining the results relevant to the scope of this review was used for the summary classification. This approach was adopted to avoid multiple counting of the same publication.

The critical literature review was conducted on the broader set of 41 sources. Its purpose was to identify and systematise factors affecting the timely completion of railway projects. The scope of data extraction and the subsequent stages of factor harmonisation and classification are presented in Table 4.

Table 4. Stages of the critical literature review and scope of data analysis

Scope of analysis	Scope of analysed data	Activities performed	Outcome
Data acquisition	Bibliographic data, study characteristics, research methods, data sources, factors affecting timely project completion	Extraction of information from publications and recording it in the database	Database for the critical literature review and factor analysis
Terminology harmonisation	Factor terminology	Semantic analysis and merging factors with the same meaning but described using different terminology	List of unique harmonised factors
Classification	Harmonised factors	Assignment of factors to a uniform category system developed for the study	Classification of factors into 12 categories
Synthesis of results	Results of all analysed publications	Comparison of research results, identification of factors reported in the analysed sources and development of a uniform classification	Uniform classification of factors affecting the timely completion of railway projects

The critical literature review was aimed at identifying and systematising factors affecting the timely completion of railway projects. The factors identified in the reviewed sources were extracted and recorded in the factor database. Not all sources included in the critical review constituted independent sources of delay factors. Some were used to provide methodological or contextual information, while others reported results derived from the same or partially overlapping research material. Where several publications were based on the same or overlapping study or dataset, the relevant publications were reviewed, but overlapping factors were included only once to avoid double counting. The factor extraction process resulted in 685 factor entries. Two entries were excluded because they represented consequences of delays rather than their causes. Consequently, 683 factor entries were retained for further analysis. A factor entry was defined as an individual factor identified in a source as affecting project duration or timely completion and recorded using the terminology applied in that source. A unique harmonised factor was defined as a factor obtained after comparing the extracted entries and merging those referring to the same cause despite differences in terminology. The harmonisation was based on the meaning of each factor in the context of the source, rather than solely on similarities in wording. Entries were merged only where they referred to the same underlying cause. Where similar terms referred to different causes or different stages of the investment process, they were retained as separate factors. The extraction, harmonisation and classification of factors were performed by one researcher. Ambiguous cases were resolved by re-examining the meaning of the factor in the context of the original source and comparing it with previously harmonised entries. The final classification was based on the underlying cause represented by the factor rather than on terminological similarity alone. Each unique harmonised factor was assigned to one category only. Where a factor could potentially be associated with more than one category, it was assigned according to the primary cause represented by the factor in the context of the source. The category boundaries were defined according to the primary source or nature of the factor, rather than its potential consequences at subsequent stages of project implementation. Examples of the terminology harmonisation and classification procedure are presented in Table 5.

Table 5. Examples of terminology harmonisation and factor classification

Original factor entries	Harmonised factor	Category
Design errors (Polish: Błędy projektowe); Documentation errors (Polish: Błędy dokumentacji); Errors in project documentation; Low quality of documentation (Polish: Niska jakość dokumentacji)	Design documentation errors	Design documentation
Excessively short completion periods imposed by contracting authorities (Polish: Zbyt krótkie terminy realizacji narzucane przez zamawiających); Too short completion period (Polish: Zbyt krótki termin realizacji); Assumption of an excessively short completion period (Polish:Założenie zbyt krótkiego czasu realizacji); Improperly estimated completion time	Unrealistic project completion time	Schedule and planning
Lack of adequate staff resources (Polish: Brak odpowiedniego zaplecza kadrowego); Lack of qualified staff (Polish: Brak wykwalifikowanej kadry); Lack of competent staff (Polish: Brak kompetentnej kadry)	Shortage of qualified personnel	Contractor
Many utilities are not detected at the start of work; Incomplete inventory or identification of utility networks (Polish: Brak pełnej inwentaryzacji lub rozpoznania sieci uzbrojenia); Underground infrastructure elements not shown on the available construction site maps (Polish: Nieujawnione na dostępnych mapach terenu budowy elementy infrastruktury podziemnej)	Unrecorded underground infrastructure	Unforeseeable physical conditions
Adverse weather conditions (Polish: Niesprzyjające warunki atmosferyczne); Weather conditions (Polish: Warunki pogodowe); Adverse weather conditions (Polish: Niekorzystne warunki atmosferyczne); Occurrence of adverse weather conditions (Polish: Wystąpienie niekorzystnych warunków atmosferycznych)	Adverse weather conditions	Weather conditions

The examples presented in Table 5 illustrate the terminology harmonisation procedure. Factor entries were merged where, despite differences in wording or level of detail, they referred to the same underlying cause of delay. The harmonised factors were subsequently assigned to one of the 12 categories developed for the study.

3. BIBLIOMETRIC ANALYSIS OF THE LITERATURE ON FACTORS AFFECTING THE TIMELY COMPLETION OF RAILWAY PROJECTS

To characterise the state of research, a bibliometric analysis was conducted for publications selected in accordance with the methodology presented in Section 2. The analysis covered publications obtained from the Scopus database and was intended to determine the dynamics of research development, characterise the geographical distribution of publications and identify the dominant research directions. The results obtained provided a starting point for the critical literature review and the development of a classification of factors affecting the timely completion of railway projects.

3.1. Characteristics of the analysed publications

A total of 32 publications meeting the adopted selection criteria were included in the bibliometric analysis. The analysis was conducted exclusively for publications selected from the Scopus database, while additional sources were included at the stage of the critical literature review, as described in Section 2.

The distribution of publications by year is presented in Fig. 2. The oldest publication dates from 2007; however, until 2018 the number of studies was small. Within the selected Scopus dataset, the annual number of publications increased from 2019 onwards, with the highest number of publications recorded in 2024–2026. In total, 25 of the 32 analysed papers were published from 2019 onwards, indicating growing interest in this topic.

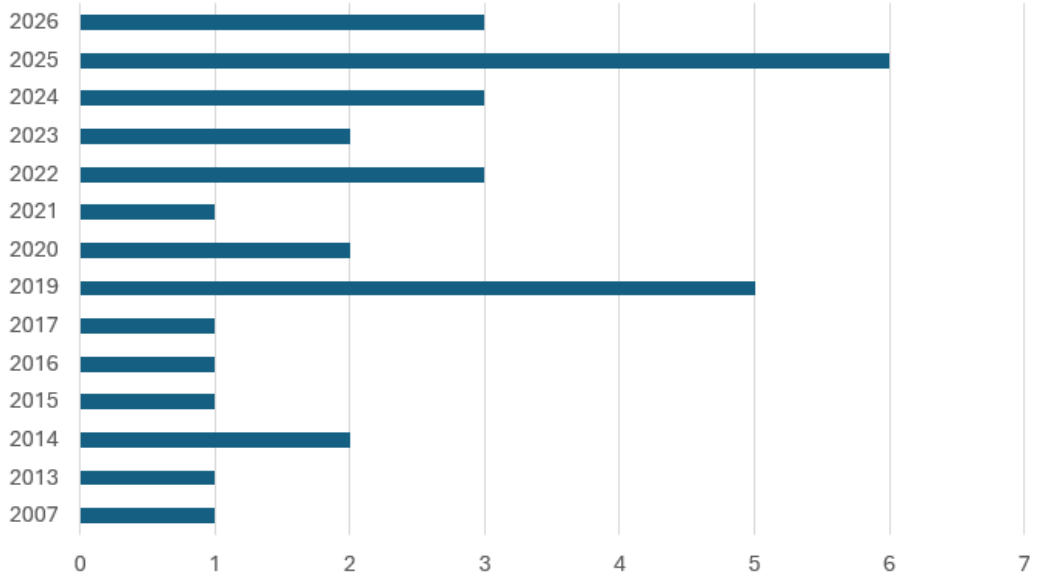

Fig. 2. Number of publications by year. Source: own elaboration based on the analysis of publications included in the bibliometric analysis. Data for 2026 cover publications indexed until 15 July 2026.

The corresponding authors of the 32 publications were affiliated with institutions in 17 countries. China and India accounted for five publications each, followed by Australia with three. The remaining publications were distributed across 14 countries.

Table 6. Characteristics of the analysed publications. Source: own elaboration

Parameter	Result
Number of publications included in the bibliometric analysis	32
Publication period	2007-2026
Number of countries represented by corresponding authors	17
Most frequently addressed research direction	Identification of factors delaying project implementation
Most frequently used research method	Surveys and expert interviews (40.6%)
Least frequently used research method	Analysis of design and contract documentation (6.3%)

The summary presented in Table 6 indicates that the analysed publications cover a period of almost twenty years and represent diverse research directions and research methods. Studies identifying

factors affecting the timely completion of projects, using surveys and expert interviews, predominate. By contrast, analysis of design and contract documentation was used only sporadically, indicating a significant research gap.

3.2. Main research directions

Based on the analysis of full texts, a classification of the main research directions addressed in the analysed publications was developed. Each publication was assigned to one dominant area corresponding to its main research objective. Where a publication addressed more than one research topic, the dominant research direction was determined on the basis of the main objective of the study. Secondary topics did not result in assignment to additional research directions, thereby avoiding multiple counting of the same publication. The classification results are presented in Table 7.

Table 7. Main research directions addressed in the analysed publications. Source: own elaboration based on the analysis of publications included in the bibliometric analysis

Publication topic	Number of publications	Share [%]
Identification of factors delaying project implementation	10	31.3
Schedule management and implementation optimisation	9	28.1
Digital tools supporting project management	6	18.7
Risk assessment and decision-support methods	5	15.6
Contract management, disputes and risk allocation	2	6.3
Total	**32**	**100.0**

The largest groups were publications concerning the identification of factors affecting timely project completion (31.3%) and schedule management and implementation optimisation (28.1%). Together, these two groups accounted for nearly 60% of the analysed publications. Issues related to the use of digital tools, risk assessment methods, and contract management and risk allocation were addressed much less frequently. The results indicate that previous research has focused primarily on identifying the causes of delays and on methods supporting project planning and implementation.

3.3. Keyword co-occurrence analysis

Keyword co-occurrence analysis made it possible to identify the main research areas and relationships between the terms used in the analysed publications. The 18 keywords included in the analysis formed three clusters comprising 7, 6 and 5 items, respectively. The network consisted of 83 links, with a total link strength of 181.

The highest total link strength was recorded for “railway” (54; 13 occurrences), followed by “railway transport” (45; 12 occurrences), “railway project” (43; 12 occurrences), “railway infrastructure” (39; 9 occurrences) and “project management” (37; 10 occurrences). “Risk analysis” occurred 10 times and had a total link strength of 25. The results show that railway-related terms form the most strongly interconnected part of the keyword network, while project management and risk analysis are also clearly represented in the analysed literature.

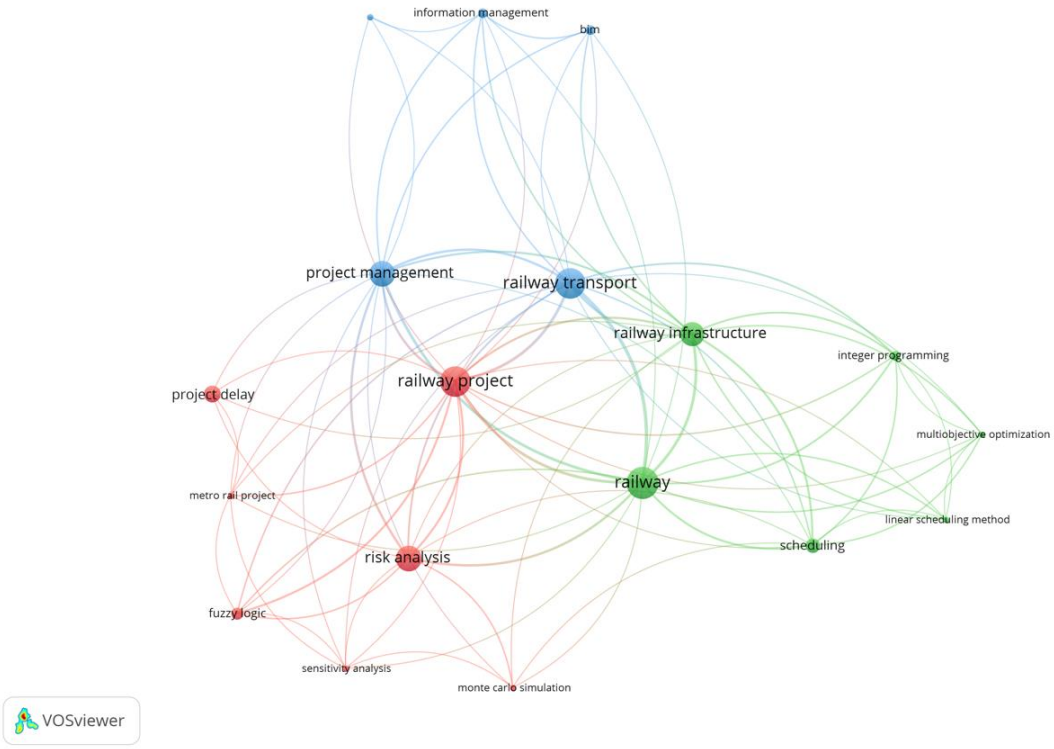

Fig. 3. Co-occurrence map of all keywords in the analysed publications (own elaboration using VOSviewer 1.6.21)

The network was divided into three clusters. Cluster 1 (7 items) comprises terms related primarily to railway projects, project delays and risk analysis, including methods used for risk assessment. Cluster 2 (6 items) is associated with railway infrastructure, scheduling and optimisation methods. Cluster 3 (5 items) includes terms related to railway transport, project management and digital information management. In the network visualisation, node size reflects the number of keyword occurrences, colours indicate cluster membership, and links represent co-occurrence relationships between keywords, with thicker lines indicating stronger links. The strength of these relationships is expressed by link strength.

Table 8. Classification of the analysed publications by dominant research method. Source: own elaboration

Research method	Number of publications	Share [%]
Surveys and expert interviews	13	40.6
Case study	4	12.5
Decision-making and risk assessment models	9	28.1
Simulations and optimisation models	4	12.5
Analysis of design and contract documentation	2	6.3
Total	**32**	**100.0**

The analysed publications increasingly use methods supporting risk analysis and project planning, such as fuzzy logic, DEMATEL, social network analysis, Monte Carlo simulations and BIM technology. At the same time, only a small number of publications address the systematic classification of factors affecting the timely completion of railway projects.

3.4. Conclusions from the bibliometric analysis

The selected Scopus dataset shows an increase in publications concerning the timely completion of railway projects in recent years. Research concerning the identification of causes of delays, risk management and methods supporting project planning predominates. At the same time, few publications attempt to comprehensively systematise the factors affecting the timely completion of railway projects. This justifies the need for a critical literature review and the development of a uniform classification of factors, presented in the following section.

4. CRITICAL LITERATURE REVIEW OF FACTORS CONTRIBUTING TO RAILWAY PROJECT DELAYS

4.1. Classification of identified factors

The critical review comprised 37 academic sources and four NIK reports. The academic sources included 17 Polish sources (45.9%) and 20 sources from outside Poland (54.1%). Classification was based on the first author's institutional affiliation associated with the publication; for doctoral dissertations, the institution where the dissertation was submitted was used. The four NIK reports were considered separately and were not included in these percentages.

The critical review resulted in 685 factor entries referring to factors affecting the timely completion of railway projects. Two entries were excluded because they described consequences of delays rather than their causes. Consequently, 683 factor entries were retained for further analysis. Following terminological harmonisation, these entries were consolidated into 552 unique harmonised factors, which were subsequently assigned to 12 categories corresponding to the main areas of the investment process. The developed classification is presented in Table 9. Table 9 also identifies the sources contributing factor entries to each category. Sections 4.2–4.13 discuss selected findings with references linked to specific studies.

Table 9. Classification of unique harmonised factors affecting the timely completion of railway projects. Source: own elaboration based on the critical literature review and harmonisation of the identified delay factors

Factor category	Scope of category	Number of unique harmonised factors	Share of unique harmonised factors [%]	Source references
Organisation and management of project implementation	Factors related to coordination, communication, decision-making, supervision, information flow and day-to-day management of project implementation.	177	32.1	[2], [3], [7], [8], [15], [16], [20], [22], [26], [27], [30], [32], [33], [35], [42], [45–48], [50–57], [59], [60]
Contractor	Factors related to the contractor's resources, experience, technical and financial capacity, personnel and ability to perform the works.	111	20.1	[2], [3], [7], [8], [15], [16], [22], [26], [30], [32], [35], [39], [42], [46–48], [50–52], [54–57], [60]
Design documentation	Factors related to the preparation, completeness, quality and coordination of design documentation, including design errors, deficiencies and design changes.	53	9.6	[3], [8], [16], [20], [22], [26], [27], [30–33], [35], [39], [42], [45–48], [50–56], [59], [60]

Administrative decisions and approvals	Factors related to administrative procedures, decisions, permits, approvals and requirements of public authorities affecting project preparation and implementation.	58	10.5	[3], [7], [8], [16], [22], [26], [27], [30–32], [42], [45], [46], [48], [50], [52–55], [59], [60]
Schedule and planning	Factors related to the preparation, assumptions, sequencing and updating of schedules and the planning of works and resources.	35	6.3	[3], [8], [15], [16], [22], [26], [27], [30], [32], [35], [39], [42], [45], [47], [51], [52], [54–57], [59]
Additional works and scope changes	Factors directly related to changes in the contractual or technical scope of works and the need to perform works beyond the originally assumed scope.	27	4.9	[8], [15], [16], [20], [22], [30], [33], [39], [42], [45–48], [50], [51], [56], [57], [60]
Access to the construction site	Factors related to the acquisition, availability and timely handover of land and work fronts required for project implementation.	24	4.3	[3], [7], [15], [22], [26], [31], [42], [46], [47], [50], [54–56], [60]
Unforeseeable physical conditions	Physical site conditions revealed during project implementation and not identified in the available project information, including ground conditions, unrecorded infrastructure and other undisclosed site constraints.	23	4.2	[7], [8], [16], [20], [22], [26], [30], [31], [33], [35], [39], [42], [48], [50], [53–57], [60]
Tender procedure and contractor selection	Factors originating from the preparation and conduct of procurement procedures and the selection of contractors.	17	3.1	[3], [16], [26], [27], [42], [45], [46], [50], [52], [54], [56], [60]
External and exceptional events	External or exceptional events largely beyond the direct control of project participants, including protests, strikes, epidemics, natural disasters, vandalism, theft and economic crises.	15	2.7	[7], [8], [22], [30], [31], [35], [42], [50], [52], [57]
Weather conditions	Factors related to adverse weather conditions affecting the possibility or organisation of construction works.	5	0.9	[3], [8], [22], [30], [31], [35], [42], [52]
Track possessions and access to infrastructure	Factors specific to railway projects related to the availability, allocation and duration of track possessions and access to operational railway infrastructure.	7	1.3	[20], [22], [26], [33], [47], [53], [54]
Total		**552**	**100.0**	

Note: References identify sources from which at least one factor assigned to the respective category was extracted. They do not imply that every source reported all factors within that category.

Where similar factors could be associated with different categories, their assignment depended on the underlying cause identified in the source. For example, inadequate site investigation resulting from deficiencies in project preparation or design documentation was classified under Design documentation, whereas physical conditions revealed during construction and not identified in the available project information were classified under Unforeseeable physical conditions. Similarly, additional works and scope changes were classified as a separate factor only where the change or extension of the scope of works was itself identified as a factor affecting project duration. Where additional works were described solely as a consequence of another identified cause, classification was based on the underlying cause.

The number and share of factors presented in Table 9 refer to unique harmonised factors identified in the reviewed sources. These values reflect the diversity of factors identified within each category and should not be interpreted as the frequency of occurrence of particular causes in railway projects or as a measure of their impact on project delays. The analysis does not establish a hierarchy of delay causes according to their frequency or magnitude of impact.

4.2. Design documentation

The design documentation category comprises 53 unique harmonised factors, accounting for 9.6% of the total set. The extracted entries concern documentation errors, incompleteness and inconsistencies, insufficient information for design, and delays in preparing or approving documentation.

Nikjow et al. [51] identified design errors, insufficient investigation before design, ambiguous drawings and incorrect interpretation of requirements by designers. Karim et al. [22] reported incomplete and inconsistent documentation, design errors and delays in providing design documents. Love et al. [39] additionally identified deficiencies in design information, including incomplete or inaccurate information on underground infrastructure.

In Polish railway studies, Połoński and Kowalski [53] identified difficulties in obtaining maps for design purposes, while Kowalski and Połoński [26] reported design documentation errors and problems with its acceptance by the Contract Engineer. The NIK report on railway station investments [46] also recorded documentation errors and delays in its preparation.

4.3. Administrative decisions and approvals

This category comprises 58 unique harmonised factors, accounting for 10.5% of the total set. It covers administrative decisions, permits, regulatory requirements and approvals involving public authorities and infrastructure operators.

Gopang et al. [16] identified difficulties in obtaining permits and approvals and requirements imposed by public authorities. Karim et al. [22] reported complex administrative procedures and delays in issuing permits, whereas Bouraima et al. [7] identified administrative barriers and regulatory instability.

In the Polish literature, Anysz and Zbiciak [3] identified lengthy administrative procedures, unclear legal provisions and prolonged arrangements with utility operators. Kowalski and Połoński [26] additionally reported incomplete legal documentation and difficulties involving internal railway approvals and infrastructure operators. The NIK report on the modernisation of selected railway lines [48] recorded delayed administrative decisions, the need to supplement administrative documentation and lengthy arrangements with infrastructure operators.

4.4. Access to the construction site

The access to the construction site category comprises 24 unique harmonised factors, accounting for 4.3% of the total set. These factors concern land acquisition, site handover and restrictions on access to areas required for construction.

Goodier et al. [15] identified delays in land acquisition in international EPC high-speed rail projects. Karim et al. [22] distinguished delays in land acquisition and site handover, restricted site access and incomplete property information. Mittal and Paul [42] also identified disputes between property owners and a lack of space for prefabrication.

In Polish studies, Leśniak and Piskorz [31] reported the absence of a legal right to use property for construction purposes and restrictions on access to parts of the site. The NIK report on railway station investments [46] recorded delayed site handover, while the report on ERTMS/ETCS implementation [47] identified difficulties in acquiring properties and obtaining the right to use them for construction.

4.5. Tender procedure and contractor selection

This category comprises 17 unique harmonised factors, accounting for 3.1% of the total set. It concerns procurement preparation, tender procedures and contractor selection.

Mittal and Paul [42] identified a lengthy contractor selection process and underpriced bids. Gopang et al. [16] reported an inappropriate choice of contract type. Tran et al. [60] identified changes in, or a lack of agreement on, applicable standards and requirements.

In Polish railway studies, Kowalski and Połoński [26] identified errors in tender and conceptual documentation and the need to depart from assumptions adopted at the tender stage. The NIK report concerning PKP PLK infrastructure investments [45] recorded delays in tender procedures and contractor selection based solely on the lowest-price criterion. Delayed tender procedures were also reported in the audit of railway station investments [46].

4.6. Contractor

The contractor category comprises 111 unique harmonised factors, accounting for 20.1% of the total set. It covers contractor experience, personnel, equipment, financial capacity, materials and work execution.

Nikjow et al. [51] identified insufficient contractor experience, equipment shortages and failures, material shortages and rework resulting from inadequate competence. Mittal and Paul [42] reported shortages of skilled labour and specialist equipment, contractor financial problems and low equipment productivity. Karim et al. [22] additionally identified liquidity problems and increases in material prices.

In Polish studies, Leśniak and Piskorz [32] identified insufficient contractor resources and experience, a shortage of qualified personnel, bid calculation errors and financial problems. Dziadosz et al. [8] reported low labour productivity, equipment shortages and workmanship errors. The NIK report on the modernisation of selected railway lines [48] also recorded shortages of contractor personnel and equipment.

4.7. Organisation and management of project implementation

This category comprises 177 unique harmonised factors, accounting for 32.1% of the total set. It covers coordination, communication, decision-making, supervision, payments, logistics and contract administration.

Goodier et al. [15] identified deficiencies in design management, subcontract administration, procurement preparation and equipment and workforce logistics. Nikjow et al. [51] reported inadequate coordination and communication, ineffective site supervision and delayed payments. Karim et al. [22]

identified slow decision-making by the client, inadequate project control and insufficient coordination with external parties.

In Polish studies, Leśniak and Plebankiewicz [30] reported delayed client decisions, communication problems, insufficient supervision and difficulties involving subcontractors. Janowiec [20] identified coordination problems at contract interfaces and inadequate organisation of works. The NIK report on ERTMS/ETCS implementation [47] recorded insufficient supervision, progress monitoring and information flow, as well as conflicts between concurrent projects.

4.8. Schedule and planning

The schedule and planning category comprises 35 unique harmonised factors, accounting for 6.3% of the total set. These factors concern completion-time assumptions, work sequencing, resource planning and schedule preparation.

Karim et al. [22] identified unrealistic schedules, incorrect estimates of project duration and inappropriate sequencing of works. Gopang et al. [16] reported inadequate planning and scheduling, unrealistic contractual completion periods and deficiencies in material delivery planning. Goodier et al. [15] also identified inadequate construction planning.

In Polish studies, Anysz and Zbiciak [3] identified unrealistic completion periods, while Kowalski and Połoński [26] reported unrealistic deadlines for both project completion and preparation of design documentation. Dziadosz et al. [8] identified scheduling errors and ineffective project planning. The NIK report on ERTMS/ETCS implementation [47] recorded unrealistic schedule planning and the absence of an approved implementation schedule.

4.9. Unforeseeable physical conditions

This category comprises 23 unique harmonised factors, accounting for 4.2% of the total set. It includes physical site constraints, ground conditions and previously unrecorded infrastructure encountered during implementation.

Karim et al. [22] identified unrecorded underground infrastructure, unforeseen site conditions and delays in relocating conflicting infrastructure. Mittal and Paul [42] reported unforeseen ground conditions and utility relocation works. Steininger et al. [57] identified adverse or unexpected geological conditions.

In Polish railway studies, Połoński and Kowalski [53] identified unrecorded underground infrastructure and hidden obstacles. Janowiec [20] reported unrecorded underground infrastructure and insufficient geotechnical investigation. The NIK report on the modernisation of selected railway lines [48] also recorded previously unrecorded infrastructure conflicts.

4.10. Track possessions and access to infrastructure

This railway-specific category comprises 7 unique harmonised factors, accounting for 1.3% of the total set. Karim et al. [22] identified the need to adapt construction works to ongoing railway traffic.

Polish railway studies provide more detailed examples. Połoński and Kowalski [53] reported difficulties in obtaining track possessions, while Kowalski and Połoński [26] identified reductions in the duration of possessions already granted. Leśniak and Janowiec [33] and Janowiec [20] identified the lack of required track possessions. The NIK report on ERTMS/ETCS implementation [47] additionally recorded technical problems with the GSM-R system, which were assigned to this category in the present classification.

4.11. Weather conditions

The weather conditions category comprises 5 unique harmonised factors, accounting for 0.9% of the total set. Karim et al. [22] reported adverse and extreme weather conditions, while Mittal and Paul [42] included weather conditions among the factors affecting project completion.

In the Polish literature, Anysz and Zbiciak [3] identified adverse weather conditions. Leśniak and Piskorz [31] reported the execution of works during winter, while Piskorz [52] identified both winter working and adverse weather conditions. Natural disasters are considered separately under External and exceptional events.

4.12. Additional works and scope changes

This category comprises 27 unique harmonised factors, accounting for 4.9% of the total set. It covers changes to the project scope and design, together with additional works.

Love et al. [39] identified scope changes, client-initiated design changes and incomplete definition of the project scope. Karim et al. [22] reported changes to documentation, specifications and the scope of works during implementation, as well as additional works. Goodier et al. [15] also identified design changes in international EPC high-speed rail projects.

In Polish studies, Janowiec [20] identified changes to design solutions introduced by the client, while Dziadosz et al. [8] reported client-initiated design changes. The NIK report on ERTMS/ETCS implementation [47] recorded changes in project scope and phasing and additional works. The report on the modernisation of selected railway lines [48] also identified additional works resulting from deficiencies in project preparation.

4.13. External and exceptional events

The external and exceptional events category comprises 15 unique harmonised factors, accounting for 2.7% of the total set. These entries are grouped for analytical purposes; their inclusion does not constitute a legal determination that an event qualifies as force majeure.

Bouraima et al. [7] identified vandalism and theft. Mittal and Paul [42] reported strikes, social unrest and economic crisis, while Karim et al. [22] identified social conflicts associated with the project and events described as force majeure.

In Polish studies, Leśniak and Piskorz [31] identified protests by residents and environmental organisations. Dziadosz et al. [8] reported protests, strikes, natural disasters and the pandemic. Leśniak [35] also identified natural disasters and protests by residents and environmental organisations.

4.14. Synthesis of results

The category of organisation and management of project implementation comprised the largest number of unique harmonised factors (177), followed by contractor-related factors (111), administrative decisions and approvals (58), and design documentation (53). These four categories show the greatest diversity of factors identified in the analysed literature. The reviewed literature also indicates that factors assigned to different categories may occur in relation to the same project circumstances, particularly where problems related to design documentation, administrative procedures or physical conditions are accompanied by additional works, changes in the organisation of works or schedule updates.

The review also showed similarities between the factors identified in Polish and international studies. Factors related to project implementation, design documentation, administrative procedures and contractor capacity were identified in both groups of publications. At the same time, factors specific to railway projects were identified, such as limited availability of track possessions and the need to carry out works while maintaining railway traffic.

The developed classification systematises the factors affecting the timely completion of railway projects identified in the literature and provides a starting point for further empirical research. It does not represent a causal model of the mechanisms leading to project delays.

5. DISCUSSION

The four categories comprising the largest numbers of unique harmonised factors account for 72.3% of the total set. This result reflects the diversity of factors identified in these areas and should not be interpreted as a measure of their frequency of occurrence or the strength of their impact on project completion time. Consequently, the analysis does not establish a hierarchy of delay causes according to their frequency or magnitude of impact. The review also showed considerable variation in the terminology used in the analysed publications. In many cases, the same phenomena were described using different terms, while identical terms were used to describe different causes of delays. The developed classification comprising twelve categories systematises these factors and may provide a reference point for further research on the timely completion of railway projects.

Compared with the individual studies discussed in Sections 4.2–4.13, which report factors within their respective research settings and classification schemes, the present study provides a cross-source synthesis. Its contribution is the explicit distinction between original factor entries and unique harmonised factors, together with common category definitions and assignment rules. The framework integrates international studies, Polish academic sources and institutional audit findings and explicitly distinguishes track possessions and access to operational railway infrastructure as a railway-specific category. It therefore complements existing approaches by facilitating comparison across sources; it does not establish a new ranking of factor importance or demonstrate predictive superiority over existing classifications.

The complete factor-level dataset is not provided with the manuscript. Although the methodological description and examples in Table 5 explain the harmonisation procedure, they do not enable readers to independently verify every harmonisation and classification decision or directly reuse the complete set of 552 factors.

The analysis showed a predominance of studies based on surveys and expert interviews, as well as the frequent use of decision-making and risk assessment models. Data reflecting the actual course of project implementation, such as schedules, design documentation, contractual correspondence or claims documentation, are used much less frequently. Consequently, a substantial part of the available knowledge is based on the opinions of project participants rather than on documents reflecting the actual course of project implementation. This phenomenon is particularly evident in Polish literature. Despite the growing number of publications concerning the timely completion of construction projects, studies based on a comprehensive analysis of contract documentation from railway projects are still lacking. This limits the possibility of understanding the mechanisms leading to delays and the relationships between individual groups of factors.

The bibliometric analysis was restricted to Scopus. As Web of Science and other databases were not searched for this component, relevant publications indexed elsewhere may have been omitted, although their number is likely to be limited given the high document-level overlap between Scopus and Web of Science in engineering (Section 2). The publication trends, keyword network and clusters should therefore be interpreted as characteristics of the selected Scopus dataset rather than of the entire research field. Sources identified outside this dataset broadened the critical review but did not remove this limitation of the bibliometric analysis.

The Polish academic sources included in the review are concentrated within a relatively small group of authors. This limits the diversity of independently represented research perspectives and should

be considered when interpreting similarities between the findings of Polish studies. Publications drawing on the same or partially overlapping research material were not treated as independent sources of repeated factor entries.

The developed classification provides a framework for further empirical research using contract records to investigate delay mechanisms and relationships between factors.

6. CONCLUSIONS

The literature review identified 683 factor entries affecting the timely completion of railway projects. Following terminological harmonisation, these were consolidated into 552 unique harmonised factors assigned to twelve categories covering the entire investment process. The developed classification systematises the diverse terminology used in the literature and provides a consistent structure for comparing factors identified in different studies. The results do not provide a basis for assessing the frequency of occurrence of individual factors, the magnitude of their impact on project completion time or for establishing a hierarchy of their importance.

The review also identified a research gap related to the limited use of data reflecting the actual performance of railway projects. In particular, studies based on a systematic analysis of contract documentation remain scarce, especially in the Polish context.

The developed classification may provide a basis for further empirical research using contract documentation to investigate the mechanisms leading to delays and relationships between individual groups of factors. The results of such analyses may support the development of methods for identifying and assessing factors affecting the timely completion of railway projects.

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