Analyzing the Evolution of Interdisciplinary Areas:
Case of Smart Cities

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ABSTRACT

Recently, various new areas of research have been of great interest to researchers. As these areas are highly based on academic and industrial needs, it is necessary to examine the change and evolution in research. This study proposed a framework for identifying emerging areas and their evolution. The proposed framework suggests that latent Dirichlet allocation is applied to identify emerging topics and their networks in such interdisciplinary areas. The simulation for empirical network analysis was then applied to the identified topic networks to terminate continuous evolution. The proposed framework is applied to a smart city, which is one of the most interdisciplinary and fast-evolving areas. These findings indicate that the evolution of smart transportation and smart grids is likely to be the focus. The findings also indicate that newly emerging research may lack openness and diversity. This study contributes to further investigate research trends and planning research strategies for new and interdisciplinary areas.

KEYWORDS

Emerging Topics, SIENA, Smart City, Text Mining, Topic Model

1. INTRODUCTION

Recently, technological convergence has become a prominent phenomenon in society. With the advancement of the Fourth Industrial Revolution, convergence is accelerated by blurring boundaries between areas. Technological convergence could trigger newly emerging areas across various industries, which could be interdisciplinary (Lee et al., 2015). These interdisciplinary areas seem to undergo prompt development, and some of them could be influential to academia and industries. Such new and interdisciplinary areas have attracted the interest of researchers in several ways. In particular, it is necessary to examine how research has changed, and how it is likely to evolve. Tracking the emergence of interdisciplinary areas can be difficult and biased because many interdisciplinary studies and their topics are continuously evolving.

Such convergences among various areas require deeper understanding for exploitation, and a data-driven approach could play an important role in not stuck one side or a subjective perspective. Such evolutions among emerging topics could deepen our knowledge to prepare for and exploit relevant changes in interdisciplinary areas. That is, identifying emerging topics and their evolution has become of interest. To address this necessity, this study proposes a framework for analyzing the evolution of interdisciplinary areas based on bibliometric data by applying text mining and simulation techniques.

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Through this framework, I expect to understand what could emerge from various opportunities and their evolutions. In particular, this study empirically applies the framework to the smart city area.

A smart city could be the frontier where industry, academia, and the daily lives of citizens are interacting. It covers diverse areas relevant to the city. Recently, the development of smart cities has accelerated with the advancement of digital transformation. It is important to carefully track its evolution to establish emerging industries and achieve continuous growth. This study attempts to provide a comprehensive and empirical approach to such convergence-triggered interdisciplinary areas.

Indeed, cities have continuously been places of innovation, and smart cities are considered an important urban platform for pursuing innovation in a sustainable economy (Chatterjee et al., 2017; Joss et al., 2019). Problem-solving with citizen participation through smart city infrastructure is expected to play a critical role in leveraging innovation. Such innovation can eventually contribute to the sustainable growth of citizens' daily lives (Su et al., 2018). A smart city is a citizen platform for solving problems highlighted in diverse areas (Maestre-Gongora & Bernal, 2019). Therefore, many researchers and practitioners now focus on smart cities, which are regarded as interdisciplinary testbeds for pursuing innovation.

Unfortunately, previous studies might be limited to comprehensively understand and predict interdisciplinary areas, where diverse sub-areas are actively interacting with each other. Previous studies have exploited various techniques for finding emerging technologies; however, unfortunately, these studies seem to lack an integrated perspective, particularly for smart cities. This study attempts to propose a framework for identifying and predicting emerging topics and their convergence from an interdisciplinary area, and this paper attempts to show its empirical application to smart cities. More specifically, it first explores emerging topics by analyzing the abstracts of interdisciplinary areas with latent Dirichlet allocation (LDA), which is a generative probabilistic model for discovering topics from given documents. Applying topic modeling to abstracts is expected to contribute to identifying emerging topics in interdisciplinary areas. Based on the yearly investigation on topic networks, the representative features of evolutions, such as openness and diversity, of these networks are empirically measured using the network simulation technique, SIENA (Simulation Investigation for Empirical Network Analysis).

The proposed framework is one of the first attempts to use topic modeling and SIENA to model topic networks and their evolution in interdisciplinary areas. The findings of this study could empirically identify emerging topics and their evolution in the case of smart cities. This paper is structured as follows: Section 2 reviews the related literature and methodologies, and the proposed framework is introduced. Section 3 explains the methodology in detail, Section 4 is devoted to the explanation of analytical results, and Sections 5 and 6 comprise the discussion and conclusions, respectively, with possible directions for further study.

2. LITERATURE REVIEW AND RESEARCH ISSUES

2.1. Understanding the Emergence of Interdisciplinary Areas

Recently, interdisciplinary science has been rapidly growing and reaching out to various domains. Its prevalence can be attributed to the continuous pursuit of expanding research boundaries and accelerated advancement across areas (Kuijer & Spurling, 2017). Indeed, the interdisciplinary nature of various sciences can enable the integration of insights by crossing the borders of diverse disciplines, and such insights are considered the key differentiating factors (Feng & Kirkley, 2020). Understanding interdisciplinary science can be exploited for diverse applications. As a result, dynamics have emerged that cover the evolutionary changes among areas based on interdisciplinary science. The exploitation and influence of interdisciplinary science are expected to be further stimulated in the future. It is necessary to understand and forecast these trends and latent issues (Viggiani & Calabro, 2020). These findings can further help researchers to effectively pursue the development of science.

However, previous studies lack a systematic understanding of the evolution of interdisciplinary sciences, which have been actively evolving and interacting with other areas. Understanding recent trends in interdisciplinary science is difficult because it is continuously changing and associated with diverse domains. This clearly reflects the multifaceted aspects of interdisciplinary science and its continuing interaction with other areas. At the same time, it poses substantial challenges to both researchers and practitioners in need of a systematic understanding of such increasingly complex research landscapes to establish future plans. This study extends the established methodological repertoire for literature synthesis by incorporating recent advances in text mining and simulation. Specifically, this study relied on topic modeling to identify latent topic structures in abstracts within interdisciplinary science.

2.2. Smart City: Interdisciplinary Testbed for Urban Problem Solving

Smart cities have attracted considerable interest from research communities and practitioners in various fields (Dameri et al., 2019). There are potentially a number of different approaches of pursuing research on smart cities in terms of concepts, methodologies, and exploitation. Some previous studies started with smart spaces, and they have focused on defining the concept of smart spaces and their architectures (Bhardwaj et al. 2018). In particular, a significant amount of research is being conducted to identify the characteristics of smart spaces and establish a strategy for effectively implementing smart cities (Bhardwaj et al., 2018, Camero & Alba, 2019; Dameri et al., 2019). Since smart cities are the primary channels for harmonizing the behavior of people with spaces and exploiting cutting-edge information and communication technology (ICT), a potential research stream could be the area of behavior modeling and information systems for smart cities. ICT for smart cities could be necessary for modeling human behavior and mining smart city data to obtain relevant insights (Camero & Alba, 2019; Leotta et al., 2015).

Recently, interest in smart cities has evolved into interest in innovation ecosystems, where the interactions between people and economic behaviors are concentrated (Nilssen, 2019). ICT-led transformations could shape the urban environment in response to global environmental changes (March, 2018). Gaffney and Robertson (2018) introduced the perspective that smart cities grew out of the implementation of North American models of suburban development, which began in the 1990s with ideas centered on smart growth and new urbanism. Smart city concepts have been combined with the growth in information technologies to create software-driven urban managerial tools for major cities.

The emergence of smart cities seems to rely on ICT advancement (Camero & Alba, 2019). Bresciani et al. (2018) pointed out that the Internet of Things (IoT) affects innovation and how technology deals with value in everyday business activities. They further regarded that such aspects were compounded in smart cities, where ICT, including IoT, could support value-added services for citizens and corporate activities to derive more business opportunities. Thus, this study could consider that the smart city covers the desires and prospects of the role of technology in solving urban issues (March, 2018).

Along with the technological advancement of smart cities, the research also focuses on the concept and issues associated with smart cities. In terms of citizenship, Cardullo and Kitchin (2019) explained that smart cities could be excessively technocratic and instrumental, and they reconsidered the concept of "citizen-centric." Smart city initiatives in Dublin, Ireland, show how most "citizen-centric" smart city initiatives could be related to stewardship, civic paternalism, and a neoliberal concept of citizenship. Yigitcanlar and Kamruzzaman (2018) also approached smart city as a vision for an ideal sustainable city platform. They further investigated the smart city practices of the UK by focusing on the achievement of sustainable urban outcomes.

Research on smart cities may require new avenues for investigation (Li, 2019). It is expected that trending smart city research will play an important role in further development. Lytras & Visvizi (2018) examined how 'Smart' its applications and solutions could be defined in an urban environment.

They raised issues regarding the effective deployment of smart city services in terms of their utility, safety, accessibility, and efficiency. They indicated that more pragmatism was necessary in research on smart cities to ensure its usefulness and relevance.

From the mentioned perspective, the smart city could be regarded as a living lab for solving problems and issues in the urban environment (Nilssen, 2019; Appio et al., 2019). Such urban living laboratories could empower local communities and make these areas more sustainable and resilient (Sengers et al., 2018). Recently, Joss et al. (2019) examined smart cities by focusing on key texts associated with cities. Their findings contribute to ongoing boundary work in smart cities. As provided by Appio et al. (2019), smart cities are evolving with efforts to increase the competitiveness of local communities through improved public services and cleaner environments.

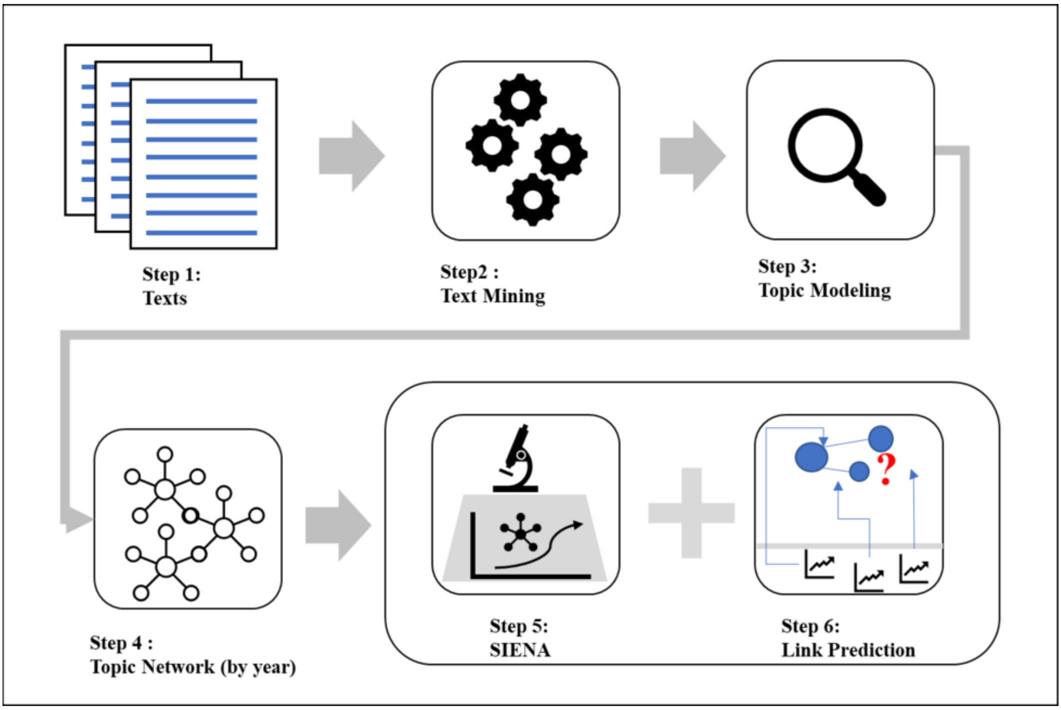
2.3. Research Issue

As mentioned above, the interdisciplinary area has recently emerged, which could bring important leverage for triggering innovation in many ways. Understanding and exploiting this interdisciplinary area could become an important question. This study attempts to identify emerging topics, their relationships, and their trends to pursue future opportunities for the sustainable growth of interdisciplinary sciences. In this context, the evolutionary trajectory of interdisciplinary areas can be regarded as the basis for continuously achieving competitiveness and industrial opportunities. The proposed approach here examines ways of pursuing sustainable development, especially in the case of smart cities. The proposed framework is somewhat different from traditional critics and reviews of the research, and it is more likely to conduct the reviewing process with text mining techniques to avoid biases that could be skewed to certain areas.

There are many techniques for bibliometric approaches, but each technique itself cannot sufficiently trend the changes in emerging topics over time. Some studies (Duan & Guan, 2021; Kim & Geum, 2021, Liang et al., 2021) have also dealt with the topic and its convergence with citations, but these are also limited because citations take a long time to appear. Recently, as topic predictions are of interest, there have been some other efforts to predict emerging topics, but they are still limited owing to the lack of temporal aspects. This paper proposes a new approach that combines existing techniques. This study attempts to systemically approach newly emerging interdisciplinary areas with temporal aspects. Interested features are measured using temporal graphs and SIENA, and based on these findings, topic link prediction is conducted.

Smart cities are good candidates for our framework in many ways, as research on smart cities has been evolving and is undergoing interdisciplinary approaches. However, although it is expected to benefit from comprehensively identifying research issues and their changing trends in smart cities, there may be a lack of consensus and integrative perspectives on understanding this complicated topic (Appio et al., 2019; Camero & Alba, 2019; Dameri et al., 2019; Nilssen, 2019). That is, our research could contribute to establishing the systematic and integrative aspects of urban problem-solving and further innovation.

Figure 1. Proposed Framework



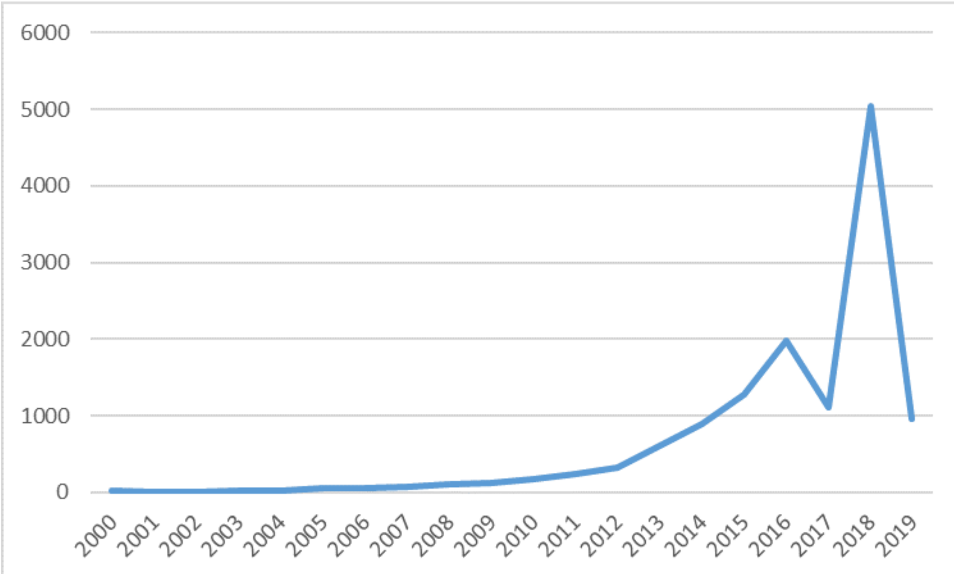
As shown in Figure 1, the proposed framework can contribute towards answering our research questions. It starts from various studies on interdisciplinary areas, continuously goes through topic modeling and simulation, and finally arrives at link prediction. A comprehensive understanding of the evolution of these research agendas and their associated interactions are important. In this study, I specify the research issues that have been discussed and evolved to predict which research issues are likely to emerge and trigger the advancement of targeted areas. Therefore, the findings of this study could provide an integrative way to understand interdisciplinary areas and discover the main streams of research topics.

3. METHODOLOGY

3.1. Data

In order to provide the empirical evidence for our proposed framework, this study obtained 13,074 abstracts of journal articles on Smart city by using the keywords, "Smart city," through SCOPUS from 2000 to 2018 as of March, 2019. This study used the search strategy of using general keywords; however, there could be some trade-offs due to the lack of some specific research indexed by other keywords. Based on this approach, it is expected to track the relevant research on various areas with an integrative perspective on smart cities, which has been interdisciplinary. The findings reveal the overall topics from smart city research to the present. The following figure shows the recent trend of increasing interest in smart cities:

Figure 2. Trends on Smart City Research



Interestingly, research on smart cities has rapidly increased since 2012. Smart city research temporarily decreased in 2017, and the number was partially represented in 2019, as the data were collected as of March 2019. However, the overall trend was increasing. As indicated in Figure 2, one can recognize the changing mood toward interdisciplinary sciences, such as Smart city in this paper, among various research institutes and related firms. Therefore, analyzing such recent trends in research could highlight their significance and business implications through the detection of emerging topics.

3.2. Topic Modeling for Trending Research

Text mining is a knowledge discovery technique that enables researchers to examine unstructured text. Many researchers have used text mining to identify trends based on unstructured texts in research abstracts. The results of such text mining can be used for various purposes. With regard to this, Feldman et al. (1998) suggested that text mining could provide the ways for effectively managing knowledge in document collections. Among the various techniques, topic modeling has been widely exploited to discern topics and clusters or to generate features in unstructured texts. Recently, LDA has been utilized for summarizing and extracting topics from unstructured texts. LDA is a probabilistic model that identifies the underlying semantic structure of documents using a hierarchical Bayesian model (Blei et al., 2003).

According to Blei et al. (2003), LDA works with topic distribution over a fixed vocabulary of terms. This technique assumes that topics are associated with various documents, and each document shows these topics in varying proportions. LDA focuses on the hidden structure of topics in given documents. The posterior distributions of these hidden topical structures can be estimated using Gibbs sampling. The findings of LDA can be further approached as a graph of topics that can be constructed by examining the relationships between topics. The graph was also clustered using a walktrap algorithm to identify similar topics. LDA can be used to effectively identify emerging technologies and research areas. Lee et al. (2015) predicted convergent technologies using link prediction and utilized LDA to extract emerging areas from the predicted technological convergence. Using LDA, Momeni and Rost (2016) analyzed trends in disruptive technology in the PV industry. Jiang et al. (2016) applied LDA to articles on hydropower to determine the current status of research trends and intellectual structures.

Through this framework, first, a text-mining technique is applied to the abstracts of smart city research. LDA, a topic modeling technique, was then used to identify emerging topics in smart cities with 10-fold cross-validation. It obtained the marginal posterior probability of each topic by year to investigate the trends for each topic. Such an evolutionary trajectory of a smart city requires open innovation to consistently pursue harmonized growth in various areas. That is, since the smart city area consists of various topics with complicated interactions, the topic relationship and its evolution over periods can lead to its dynamic growth for further innovation. In particular, a lack of understanding of the time-varying aspects of smart cities could make it difficult to effectively achieve innovation and economic growth.

3.3. Temporal Analysis on Topic Networks

The discovered topics could be related to others, and these could reveal the topic network for each year. Based on such networks over time, temporal analysis is necessary to understand the changing nature of interdisciplinary areas. This study examined the following characteristics of network interactions: density, degree, reciprocity, and transitivity. The density shows the density of the relations existing in the network over all possible relations. The degree explains the extent of diversity of the research topic and its association with other topics, which can be interpreted as the diversity of change in networks according to Johnson et al. (2009). Reciprocity represents mutualism, similar to the species symbiosis in Johnson et al. (2009), represents the interdependency of research topics. Transitivity represents the openness of network evolution, and low-transitive triplets indicate that network evolution is open to other new areas.

Thus, there is still a need to investigate the time-varying aspects of topic networks. Then, to effectively understand the temporal change in topics and their interactions with other topics, it further attempted to apply the temporal analysis of topic networks. This study examines how topic networks have evolved over the years, using SIENA. SIENA is widely used as a statistical estimation of models for repeated measures of social networks (Snijders, 2001; Jhonson et al., 2009). SIENA, the statistical estimation of models for repeated measures of social networks, was recently utilized to address time-varying changes in network representation of various relationships, such as social, scholarly, and ecological networks, with statistical modeling to examine network effects, including the openness and diversity of network evolution (Snijders, 2001). In particular, SIENA could provide an analysis of the direction and rate of network evolution by assuming that networks have a continuous-time Markov chain property, and this study can conduct it using RSiena.

Model estimation using the Monte Carlo procedure is conducted by generating many random networks as a null model, and the observed network can be statistically tested against the null model. SIENA can explain the various perspectives of network changes, that is, how fast and in which direction networks have been changing. SIENA measures network changes by maximizing the given objective function, which is the weighted sum of network effects and their coefficients to be estimated through simulation (Snijders, 2001). It also produces sets of estimates of parameters and standard errors with the assumption of an approximate standard normal distribution, and this approximation enables us to statistically test the hypothesized network effects (Snijders, 2005).

Various network effects have been provided by SIENA to understand the diverse perspectives of temporal changes in topic networks. In this study, I further attempt to concentrate on the basic network effect, the rate of network change, among the many network effects. The rate parameter mentioned above indicates the structural changes in networks by considering the expected number of changes per node in the network, and it is estimated using the conditional method of moment. The rate parameter provides the rate of change of network evolution, which represents the speed of evolution (Snijders, 2005).

3.4. Link Prediction

One of the purposes of this study is to predict the changes in the networks of discovered topics. To examine whether each topic was prevalent, the linear slope for each topic was measured by regressing the topic probability for the year. Based on these findings, this study identified hot and cold topics based on their linear slope. Subsequently, link prediction can be applied to our topic networks of interdisciplinary areas. Link prediction is a technique that can predict possible links between existing links in a network (Bai et al., 2021; Liben-Nowell and Kleinberg, 2007; Karimi et al., 2021; Lee et al., 2015). Link prediction has been widely utilized in many areas; for example, it has been adopted to analyze convergent emerging areas (Lee et al., 2015). It is further applied to discover the technology opportunity based on the network of technological areas (Lee et al., 2021). In addition, link prediction is improved for resolving the privacy issue when the predicted results are utilized in social network services (Kou et al., 2021). There are also developments of link prediction algorithm, and, especially, predicting links over time is of many researchers' interests (Bai et al., 2021). For instance, Ghorbanzadeh et al. (2021) considered the temporal aspects for link prediction. They proposed the method to capture the status of social network as an instant image and predict links of that image with the new similarity measure. The new source of information is identified to leverage the link prediction. Karimi et al. (2021) provided the use of new source of information for predicting links. Their suggestion relies on both the network information and the external information, such as the community information.

The current paper attempts to focus on the link prediction of temporal networks and improve the similarity calculation. The detailed approach is shown in Figure 3.

Figure 3. Link Prediction in detail

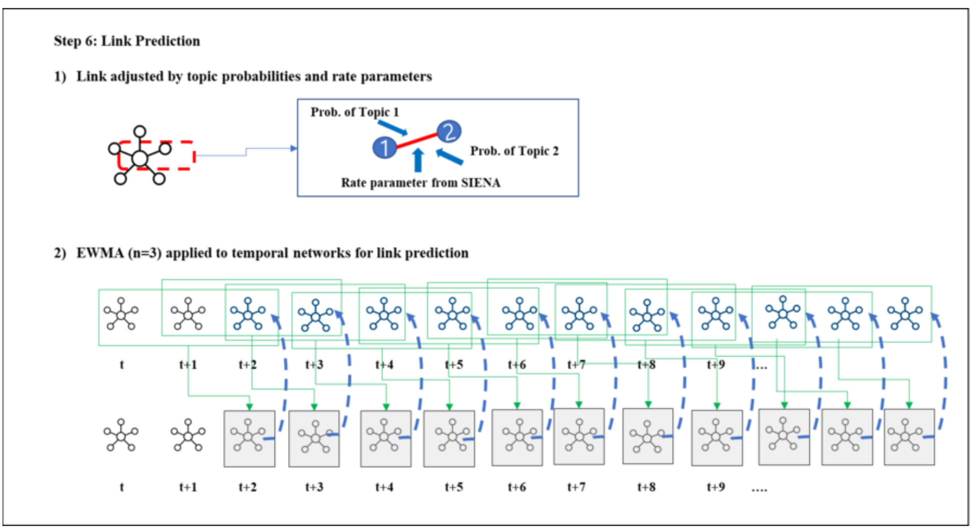


Figure 3 shows the link prediction step in more detail. First, it attempts to predict topic convergence based on temporal topic networks. The edge of a network is critical for link prediction. If the edge lies between important topics and belongs to the actively changing network, then that edge can be weighted by topic probabilities and the change of graph over period, which can be measured by the rate parameter. Second, because the temporal networks are connected as a chain, EWMA with n=3 is consecutively applied to temporal graphs. The EWMA network is updated, and this process continuously accumulates throughout the entire network.

To apply link prediction, the similarity between the nodes of the targeted graph must be measured in advance. Therefore, it is crucial to consider an appropriate similarity measure. For link prediction, this study considered the use of Adamic/Adar similarity. This similarity was proposed to examine the similarities between websites. It assigns higher weights to common neighbor nodes that are infrequently found (Adamic & Adar, 2003; Liben-Nowell & Kleinberg, 2007). The adamic/adar similarity in this study was obtained as follows:

$$\text{Adamic \& Adar Similarity}\left(\text{x}, \text{y}\right) = \sum\nolimits_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{\log\left|\Gamma\left(z\right)\right|}$$

Here, Γ(x) indicates the neighbors of node x in the graph, which are the identified topics related to the smart city, and z shows a common neighbor between the two nodes x and y, which is the link between the smart city topics. This similarity could weigh more common links between nodes, and such interactions between topics could positively affect the topic convergence. The more common the adjacent nodes are, the more similarities exist between the nodes of the graph. In this study, the linear slope for each topic was obtained by regressing the topic probability for each year. These linear slopes were applied to the recent topic network to adjust topic probability. Then, the aforementioned link prediction is applied to derive the emerging topic convergence.

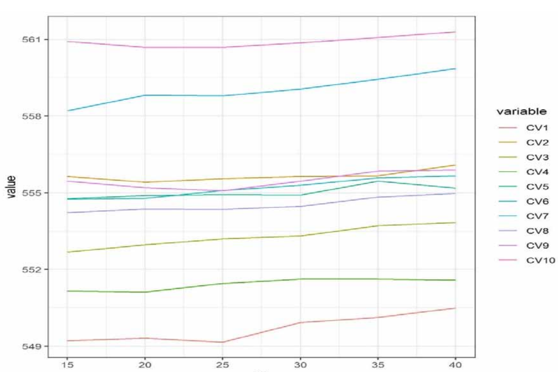
4. EMPIRICAL ANALYSIS

4.1. Topic Discovery with LDA

This study first applied LDA to identify topics from the research on smart cities. For LDA, an empirical Bayesian method was used for parameter estimation. A topic model was constructed based on the abstracts of smart city research using statistical software R. To reduce irrelevant terms in the text data, uninformative elements, such as conjunctions, determiners, prepositions, and numbers, were removed. A term-by-document frequency matrix was built to analyze the abstracts of smart cities.

To determine the appropriate number of topics, a perplexity measure was deployed. Perplexity is a decreasing function of the log-likelihood of the topic model, given the estimated parameters. Perplexity has been widely used to select the optimal number of topics when using cross-validation. The number of topics was chosen where the perplexities from the 10-fold cross-validation of the testing documents were mostly low, as shown in Figure 4.

Figure 4. Perplexity by Number of Topics (K) with 10-fold cross-validation.



A lower perplexity indicates a better general performance. Figure 4 shows perplexity based on the number of topics (K). The average perplexity of topics was the lowest at topic number 25; therefore, 25 was considered the optimal number of topics that were within the limits of possibility. It observed 25 different topics in smart-city research.

The resulting topics are listed in Table 1. Below. Each topic can be represented by "most probable" terms and topic labels can be assigned using these terms. The topics based on the 25 words with the highest probability of occurrence for each topic are listed in Table 2. The following topics labelled and reviewed by the relevant experts through smart city forum.

Table 1. Topics on Smart city

#	Most Probable Terms (Stemmed)	Label
1	social,govern,public,citizen,innov,communiti,particip,open,collabor,local,univers,media,educ,creat,strategi,stakehold,knowledg,engag,cultur,student,contribut,success,practic,promot,ecosystem	Living lab: Innovation ecosystem within local communities and universities
2	smart,concept,infrastructur,definit,initi,citizen,life,discuss,term,dimens,develop,world,vision,resid,explain,make,holist,idea,substanti,scope,aspect,characterist,essenti,attempt,effort	Smart infrastructure
3	detect,learn,featur,predict,imag,techniqu,posit,propos,machin,accuraci,video,estim,classif,recognit,track,extract,local,train,dataset,camera,classifi,experiment,accur,signal,neural	Video recognition and classification using Deep Learning
4	servic,mobil,inform,provid,access,share,locat,recommend,content,experi,applic,smartphon,custom,prefer,onlin,app,deliv,person,discoveri,enabl,request,interfac,exploit,call,web	Mobile services recommendation via online interfaces
5	comput,secur,resourc,cloud,privaci,scheme,mechan,provid,attack,distribut,protect,effici,requir,edg,util,server,trust,authent,paper,share,fog,function,ensur,threat,dynam	Mobile edge computing with security issues
6	solut,challeng,infrastructur,emerg,address,issu,requir,provid,manag,potenti,current,face,respons,futur,benefit,increas,critic,limit,offer,paradigm, promis,disast,major,complex,lead	Problem solving in cities (i.e., disasters)
7	research,studi,identifi,relat,paper,investig,analysi,find,focus,review,explor,understand,discuss,practic,factor,impact,survey,adopt,purpos,examin,analyz,field, suggest,contribut,futur	Analysis and survey of Smart city
8	network,sensor,communic,wireless,node,protocol,propos,transmiss,deploy,rout,simul,perform,delay,connect,channel,distribut,reliabl,packet,wsn,scenario,receiv,topolog,scheme,radio,coverag	Sensor Wireless Network technology
9	activ,human,work,live,behavior,health,individu,improv,life,experi,environ,make,daili,assist,enhanc,state,provid,action,healthcar,behaviour,care,import,effect,medic,identifi	Healthcare
10	technolog,inform,develop,digit,communic,intellig,ict,advanc,futur,world, reserv,integr,play,discuss,societi,transform,global,trend,vision,field,modern,creat,realiz,technic,enhanc	Intelligent ICT systems
11	qualiti,monitor,area,increas,water,improv,high,condit,environment,pollut,air,signific,result,measur,import,temperatur,cover,affect,continu,addit,life,observ,rang,order,nois	Managing air and water pollution-Environmental technology

Table 1 continued on next page

Table 1 continued

#	Most Probable Terms (Stemmed)	Label
12	data,collect,big,process,event,analyt,generat,larg,sens,sourc,realtim,senso r,stream,pattern,analysi,mine,visual,databas,aggreg,queri,inform,crowd,p roduc,spatial,spatiotempor	Spatiotemporal analysis on crowd generating sensor data
13	develop,author,construct,industri,structur,design,engin,scienc,project,publish, market,risk,form,includ,materi,state,establish,properti,field,compani,edp,orga n,enterpris,technic,stage	Designing and examining industrial structures
14	result,evalu,method,perform,effect,analysi,show,measur,test,characterist,c ompar,paramet,indic,assess,determin,calcul,obtain,factor,index,similar,va lu,type,conduct,statist,final	Quantitative approach-Evaluation & statistical analysis
15	algorithm,propos,perform,optim,result,show,improv,task,cluster,simul,effic i,solv,number,schedul,compar,reduc,minim,achiev,strategi,code,cost,constr aint,experiment,parallel,memori	Optimization algorithm with parallel processing
16	present,part,work,main,intern,point,wast,concept,import,publish,switzer land,consid,relat,order,aim,view,direct,recent,issu,aspect,take,attract,inte rest,term,element	Smart city cases-Switzerland
17	urban,develop,sustain,plan,polici,econom,area,region,growth,popul,global,spa tial,environment,strategi,nation,european,green,india,economi,transit,climat,as sess,impact,transform,goal	Planning regional economic development
18	approach,framework,process,present,tool,support,decis,implement,propos,sce nario,complex,integr,methodolog,specif,order,defin,requir,demonstr,appli,intr oduc,general,domain,step,aim,illustr	Framework for decision support
19	energi,power,effici,consumpt,electr,grid,demand,generat,distribut,reduc,u til,cost,optim,suppli,save,renew,consum,charg,heat,storag,emiss,solar,batt eri,reduct,simul	Smart grid
20	iot,devic,smart,internet,thing,applic,connect,home,enabl,sensor,monitor,capa bl,paradigm,environ,actuat,remot,communic,interconnect,embed,autom,make ,rfid,deploy,heterogen,equip	IoT & Smart devices for home
21	system,manag,control,oper,design,intellig,function,integr,implement,paper,mo dul,autom,test,coordin,realiz,consist,realtim,respons,remot,complet,autonom, maintain,adapt,cyberphys,enhanc	Intelligent real-time & autonomous cyberphysical system management-Digital twin
22	model,approach,topic,dynam,knowledg,semant,inform,program,map,web,rea son,analysi,ontolog,proceed,discuss,rule,languag,link,process,represent,speci al,complex,logic,fuzzi,game	Dynamic knowledge base and ontology-Natural language processing
23	space,environ,smart,context,interact,design,physic,virtual,adapt,ubiquit,comp ut,pervas,agent,prototyp,intellig,contextawar,interfac,awar,robot,situat,compo n,capabl,realiti,ambient,support	Virtual and physical environment-Interaction with context aware agents and robots
24	architectur,platform,design,implement,softwar,integr,support,standard,deploy, compon,develop,layer,present,enabl,domain,open,scalabl,interoper,heterogen, multipl,hardwar,demonstr,describ,facilit,flexibl	System architecture and standard for scalable & flexible hardware & facilities
25	traffic,transport,vehicl,time,road,light,park,safeti,flow,rout,public,con gest,propos,car,travel,drive,vehicular,street,simul,station,locat,condit,i ntellig,speed,bus	Smart transportation

The discovered topics are related to infrastructure (Topics 2, 19, 21, 24, 25), associated technology (Topics 3, 5, 8, 10, 11, 22, 23), related industries (Topics 13, 16, 17), services in smart city (Topics 1, 4, 6, 9, 20), and topics on analysis (Topics 7, 12, 14, 15, 18). Such findings correspond to the previous studies on smart city. In fact, infrastructure and associated technology topics play the important role for smart city development (D'Aniello et al., 2020; Ismagilova et al., 2020; Perng & Maalsen, 2020; Tanwar et al., 2018). Based on the infrastructure, smart city is closely related to the industrial aspects and services for citizens (Jiang et al., 2020; Salim et al., 2020; Serrano, 2018), and the relevant analytics are critical for the development of smart city (Barthélemy et al., 2019; Moustaka et al., 2018; Soomro et al., 2019). In particular, topics 1, 6, 21, and 23 seem to indicate the concept of a living lab in a smart city that provides data-based problem solving in a smart city and its ecosystem. Regarding the technology for a smart city, Topic 3 shows video recognition and classification using deep learning techniques. Mobile edge computing was approached as a security issue (Topic 5), and sensor wireless networks were of interest (Topic 8). Topic 10 is about intelligent ICT systems, and air pollution-related technology is specifically considered. Natural language processing (Topic 22) and context-aware agents and robots exist (Topic 23). Smart cities are expected to have advanced infrastructure. Topic 2 indicates smart infrastructure and interest is specified in the smart grid (Topic 19). Infrastructure is expanding to digital twins (Topic 21), and Topic 25 shows smart transportation. There are areas of system architecture and standards for hardware and facilities (Topic 24).

Starting with technology and infrastructure, there are topics related to industry, services, and analysis for smart cities. With regard to industry, Topic 13 explains the design and examination of industrial structure, Topic 16 provides smart city cases, and Topic 17 is about planning regional economic development. Additionally, these newly formed services can be identified as topics. Topic 1 concerns the living lab concept, which provides the innovation ecosystem within local communities and universities. Topic 4 indicates mobile service recommendations via online interfaces. It also found topics related to problem solving in cities (Topic 6). Healthcare is an important issue (Topic 9), and IoT and smart devices for homes (Topic 20) are also of interest. Furthermore, there were five topics in the analysis of smart cities. Topic 7 concerns the analysis and surveys of smart cities. The spatiotemporal analysis of crowd-generating sensor data is discussed in topic 12. The quantitative approach (Topic 14), optimization algorithms with parallel processing (Topic 15), and frameworks for decision support (Topic 18) were studied in the smart city context.

4.2. Topic Network Over Given Periods

Next, the topic network was constructed by multiplying the topic-term and term-topic matrices. This study tracked the directions of topic relations by dividing each row of the topic-topic matrix by the sum of the values of each row, based on Wasserman and Faust (1994). Topic clusters were also marked on the graph using the walktrap algorithm. As a result, it built 19 graphs of topics from 2000 onward, as shown in Figure 5a to 5d.

Figure 5. (a) Topic Networks over periods.

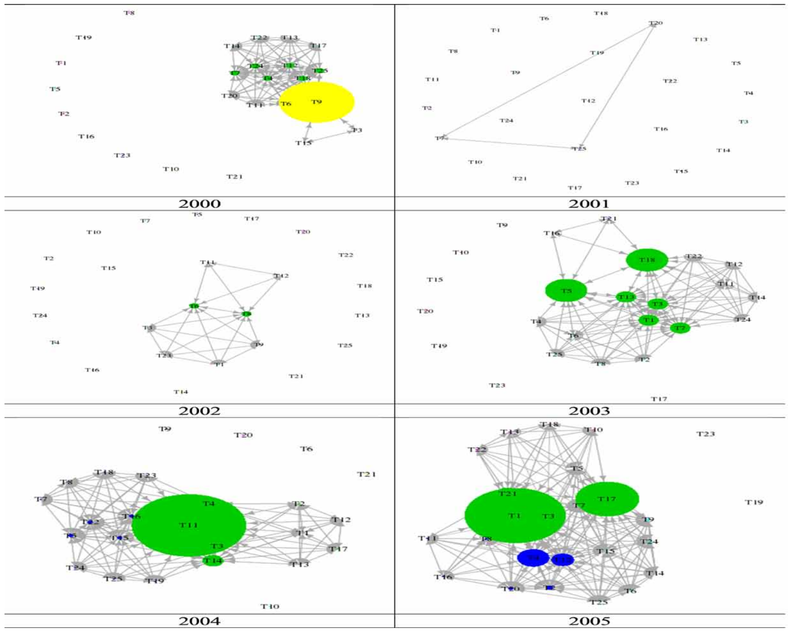


Figure 5. (b) Topic Networks over periods.

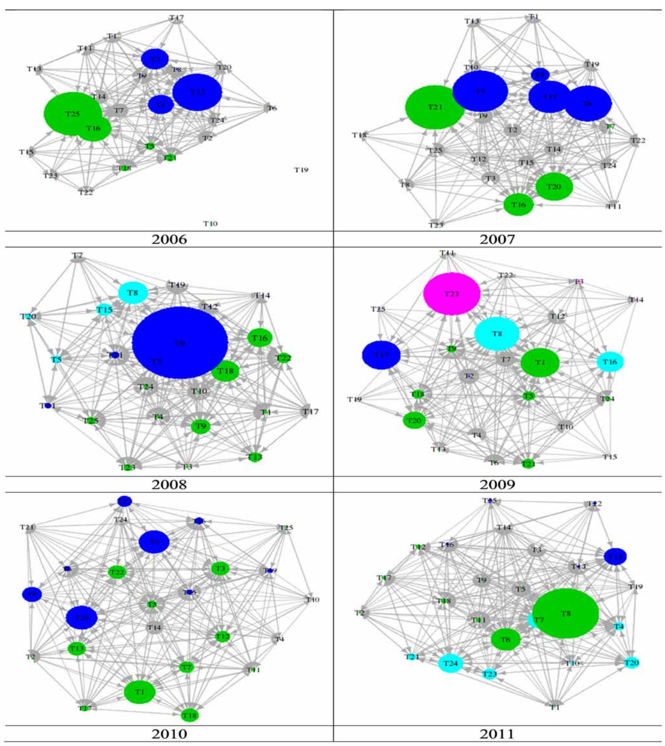


Figure 5. (c) Topic Networks over periods.

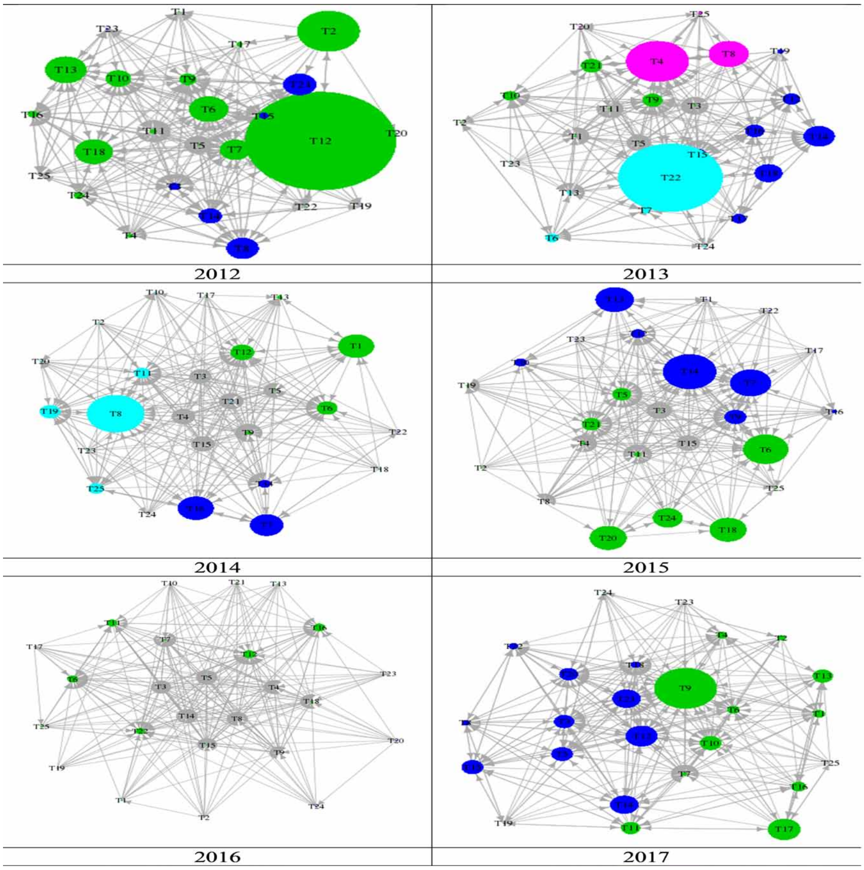
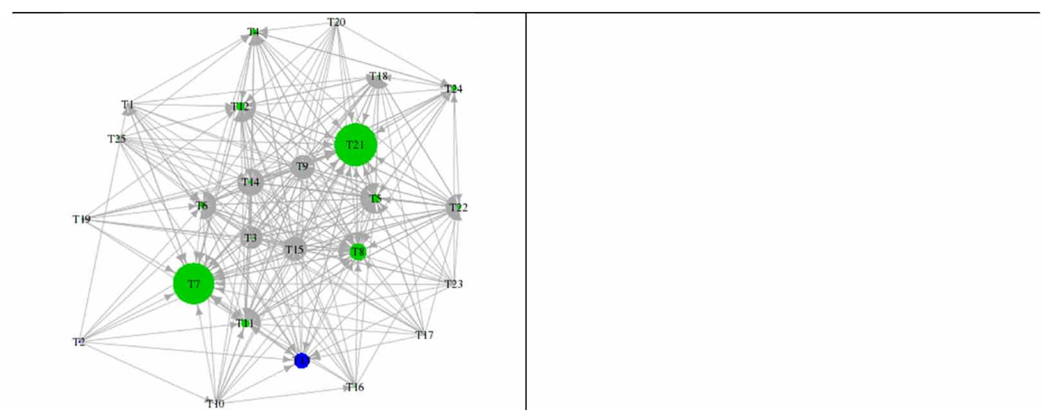


Figure 5. (d) Topic Networks over periods.



In 2000, healthcare (Topic 9) was prevalent. Surveying smart cities (Topic 7), IoT and smart devices (Topic 20), and smart transportation (Topic 25) appeared in 2001. The living lab approach (Topic 1), solving urban problems, such as disasters (Topic 6), and Sensor Wireless Network (Topic 8) were of interest in 2002, and there are many emerging topics, such as mobile edge computing with security issues (Topic 5) and Framework for decision support (Topic 18) in 2003. With the increased emergence of managing air and water pollution (Topic 11) and quantitative approaches (Topic 14), it could observe the expansion of some topics, such as Living lab approach (Topic 1), Video recognition and classification using Deep Learning (Topic 3), Mobile services recommendation (Topic 4), Spatiotemporal analysis on crowd-generating sensor data (Topic 12), planning regional economic development (Topic 17), and Digital Twin (Topic 21) in 2005.

Video recognition and classification using deep learning (Topic 3), mobile services recommendation (Topic 4), Industrial Structures Related Issues (Topic 13), Smart City cases, that is Switzerland (Topic 16), and smart transportation (Topic 25) were further interested in 2006, and subsequently the interest shifted toward mobile edge computing with security issues (Topic 5), solving urban problems, that is disasters (Topic 6), Smart city cases, that is Switzerland (Topic 16), Planning regional economic development (Topic 17), IoT & Smart devices (Topic 20), and Digital Twin (Topic 21) in 2007. In 2008, solving urban problems, such as disasters (Topic 6), Sensor Wireless Networks (Topic 8), Health care (Topic 9), Smart city cases, that is Switzerland (Topic 16), and Framework for decision support (Topic 18) were focused in this area. The findings demonstrate the diversification of this area from 2009 to 2010.

Then, solving urban problems, that is, disasters (Topic 6), Sensor Wireless Network (Topic 8), Industrial Structures Related Issues (Topic 13), and (Topic 24) were specified in 2011, and the research interests spread over (Topic 2), solving urban problems, that is, disasters (Topic 6), Sensor Wireless Network (Topic 8), spatiotemporal analysis on crowd generating sensor data (Topic 12), industrial structures related issues (Topic 13), quantitative approach (Topic 14), and framework for decision support (Topic 18) in 2012. Some new topics, such as mobile services recommendation (Topic 4), quantitative approach (Topic 14), framework for decision support (Topic 18), and dynamic knowledge base and ontology for natural language processing (Topic 22) arose in 2013, and the research moved towards Living lab approach (Topic 1), surveying smart cities (Topic 7), sensor wireless networks (Topic 8), and smart city cases, that is, Switzerland (Topic 16) in 2014. Recently, minor changes were observed in topic networks from 2015 to 2016. Health care (Topic 9) seems to be central to the development having interactions with many other topics in 2017, and surveying smart cities (Topic 7) and Digital Twin (Topic 21) were highlighted in 2018.

As mentioned above, the topic probability represents the weight of the edges on the topic network. Then, it represented the topic networks up till 2018 to effectively represent the evolution of research topics for the case of a smart city. Based on the topic networks over time, it further investigated how the networks had changed using SIENA. It could provide information on how research in smart cities has evolved. For simplicity and the application of SIENA, topic networks were preprocessed to obtain a dichotomized value. Because this study focused on the changes in topic prevalence, it compared the topic probability at the current time with that of the previous time for the simplicity and clarity of the research. If the topic probability exceeded that of the previous time, it was converted to one. Otherwise, the topic probability is converted to 0. Among various network effects of SIENA, this paper, in particular, focuses on the evolution related effects, such as rate, density, openness, and transitivity.

Next, SIENA is fitted to topic networks over time. The results of the rate of network change after simulating our SIENA model are summarized in Table 2.

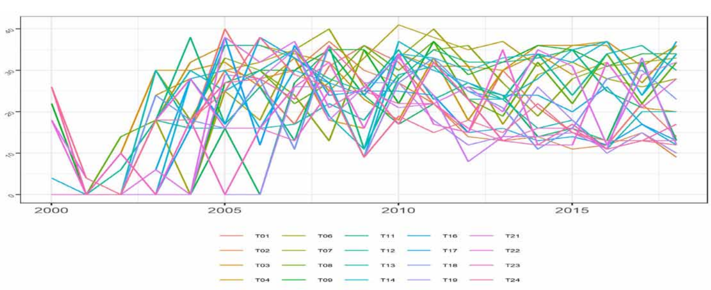
Table 2. Network effects for each transition in SIENA

	2001 to 2002	2002 to 2003	2003 to 2004	2004 to 2005	2005 to 2006
Rate (Std. err.)	20.1426 (2.7168)	3.9672 (0.9188)	66.6936 (25.0672)	159.5287 (1813.9542)	657.9290 (1881.7922)
t-value	-0.0422	-0.0526	0.0901	-0.4254	-4.6749
Wave	**2006 to 2007**	**2007 to 2008**	**2008 to 2009**	**2009 to 2010**	**2010 to 2011**
Rate (Std. err.)	337.2191 (161.3629)	581.0046 (1707.9219)	635.7355 (1548.4550)	588.0838 (1414.4622)	528.5070 (114.1459)
t-value	-2.671	-5.0633	-6.6124	-6.6533	-6.0274
Wave	**2011 to 2012**	**2012 to 2013**	**2013 to 2014**	**2014 to 2015**	**2015 to 2016**
Rate (Std. err.)	641.8070 (1304.4257)	486.2346 (1444.1423)	695.8590 (1357.8802)	603.4156 (584.5779)	594.1492 (576.7927)
t-value	-6.3615	-4.7554	-7.6358	-6.5396	-7.2384
Wave	**2016 to 2017**	**2017 to 2018**			
Rate (Std. err.)	184.6193 (1401.8875)	834.9896 (378.9597)			
t-value	-1.5531	-13.0547			
Total of 3,815 iterations / Maximum Likelihood by MCMC simulation / Robbins-Monro algorithm					

When it examined the periodical tendency of the evolution of smart city research, the rate parameters were maintained at a high level from 2005. Most of the estimated rate parameters were interpreted as statistically significant because the t-statistics of the rate parameter below 0.1 could be interpreted as significant according to Snijders (2005). The estimated values of the rate parameters indicate that the degree of topic interactions increased quickly in the interested area (Snijders, 2005). The findings reveal that the research issues have been vigorously changed, interacted, and evolved.

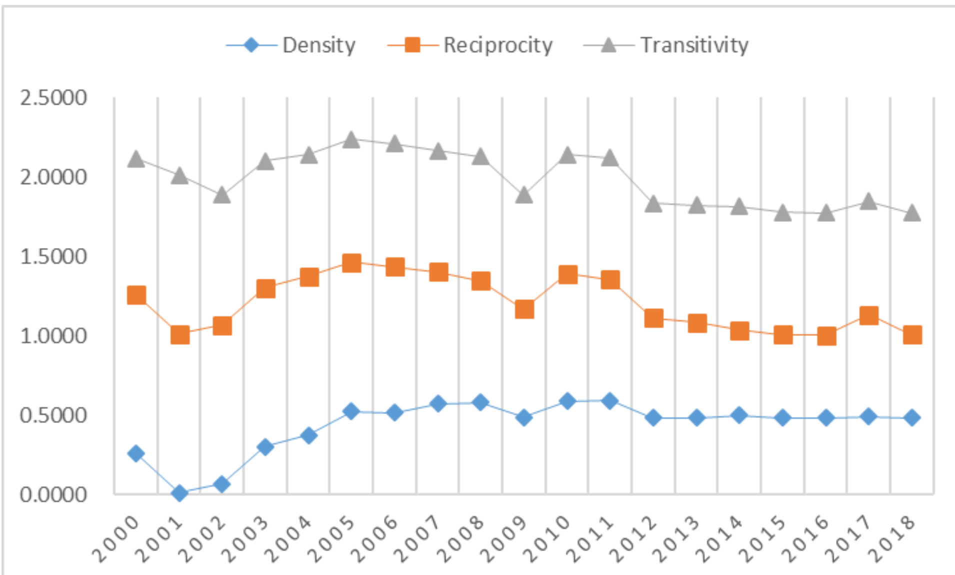
Temporal analysis was conducted on the detected 19 networks in the evolution of interdisciplinary areas. Then, to specify these findings on network changes, we further investigate some characteristics of topic networks, such as degree, density, reciprocity, and transitivity. The degree indicates how each topic is interacting with others, and the following figure shows that the average degree of a topic is about 20. The level of interaction is relatively high in some topics, such as video recognition and classification using deep learning, surveys of smart cities, healthcare, optimization algorithms with parallel processing, and digital twins, which also show an increasing trend.

Figure 6. Degree Trends of Each Topic



There were also some interesting findings regarding these network changes. First, it shows a high network density of approximately 0.5, which means that this interdisciplinary area has not reached the mature status of its evolution. They had more opportunities to interact among topics. Second, reciprocity indicates a continuous decreasing trend, which means that smart cities maintain and expand the openness of their ecosystems. Transitivity, which means how solid the network is, has also decreased, so the current topic networks of smart cities are likely to change. Thus, the possibility of more interactions among topics could be derived, and such changes could be open to new topics emerging from the smart city ecosystem.

Figure 7. Network Characteristics over periods.

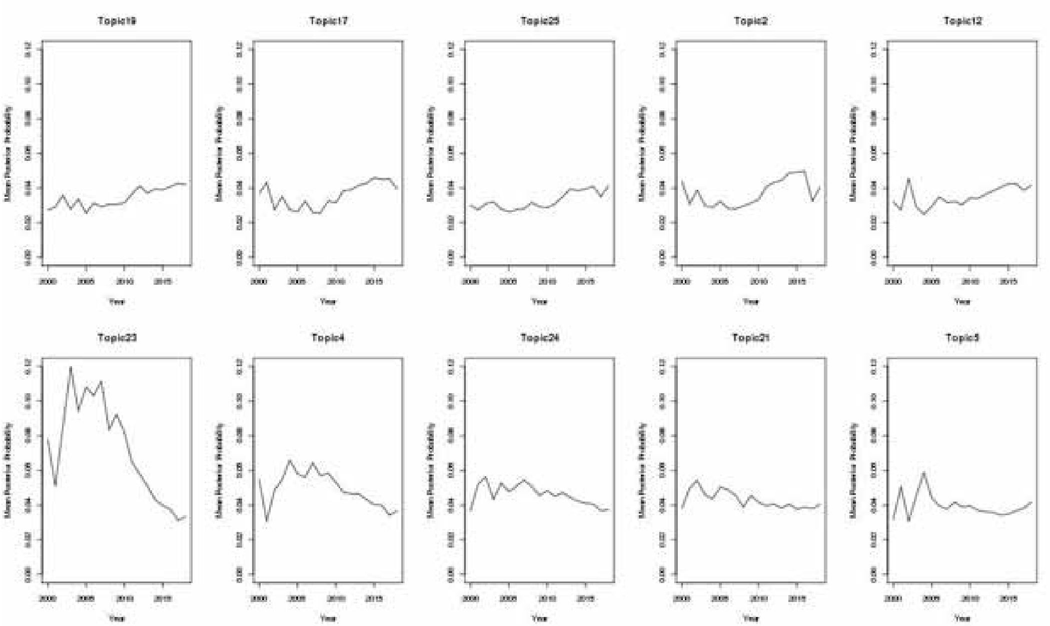


The results showed that the openness of research was somewhat high and the research was not yet stuck while it underwent fast-changing interactions. Research interaction tended to be selective for specific topics. Therefore, the research evolution might lack solid ground for its development, and it might be weak to dynamic stimuli from outside. This aspect might negatively affect the large-scale R&D planning of smart cities by focusing on certain areas. More participation and opportunities of third parties leveraged by open ecosystems could be necessary to compensate for such a risk of instability. This also highlights the necessity of predicting changes in the topic network.

4.3. Link Prediction

In this section, I analyze the emerging trends in each topic over time and predict topic convergence. The trend of each topic was examined by conducting linear regression, and the average probability of each topic by year was obtained. Each topic showed a positive or negative slope each year, indicating an increasing or decreasing trend for each topic related to the smart city.

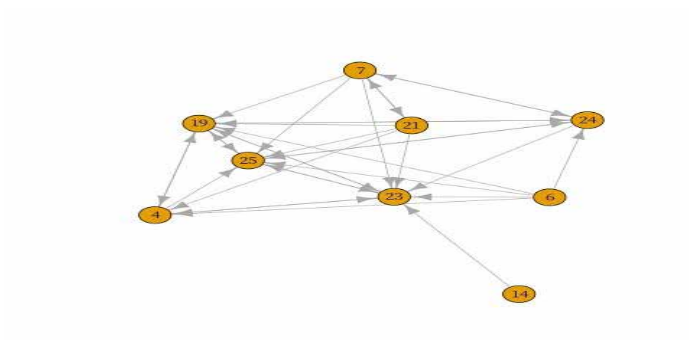
Figure 8. Top 5 Hot Topics and Top 5 Cold Topics with Linear Slope



As shown in Figure 8, overall trends in the topics over time were observed. In Figure 8, the topic probability is on the y-axis and its variability decreases from past to present. The hot topics that have increasingly appeared are as follows: smart grids, planning regional economic development, smart transportation, smart infrastructure, and spatiotemporal analysis of crowd-generated data. On the other hand, the emergence of the following topics has been decreasing: natural language processing, mobile service recommendation, system architecture and standards, digital twins, and security issues.

To apply recent variability to the analysis, this study used the recent probability of topics to modify the weight. In particular, it was assumed that recent variations were more important than past ones. Thus, the linear slope for each topic was applied to the recent topic network to adjust for the recent variations. As a result, link prediction was conducted, and the result is shown in Figure 9.

Figure 9. Link Prediction (Adamic/Adar Similarity) for Smart cities



As shown in Figure 9, findings show the result of link prediction, which could be summarized as robots, smart transportation, smart grid, and their applications for handling with disasters. The followings explain the predicted convergences more in detail. First, findings reveal that Context aware agent or robots (Topic 23) is one of the most important topics in Smart city, and this topic is expected to converge with problem solving (i.e. disaster, Topic 6), Survey and quantitative approach in smart city (Topic 7 and Topic 14), digital twin (Topic 21) and system architecture and standard for hardware and facility(Topic 24). Second, smart transportation (Topic 25) is appeared as the important part of smart city. It is likely to be converged with mobile service recommendation (Topic 4), problem solving (i.e. disaster, Topic 6), survey and quantitative approach in smart city (Topic 7) and digital twin (Topic 21). In addition, the effective and impactful mobility becomes our great interest in the future city prospect. Third, smart grid (Topic 19) seems to converge with problem solving(i.e. disaster, Topic 6), survey and quantitative approach in smart city (Topic 7) and digital twin (Topic 21). Fourth, Figure 9 shows that there are solid links among disasters (Topic 6), context aware robots and agents (Topic 23), and system architectures and standards (Topic 24). Also, the solid convergences among digital twin (Topic 21), context aware robots and agents(Topic 23), and Smart Transportation (Topic 25).In summary, smart transportation-based convergences and smart grid-based convergences are primarily predicted. There could be convergences between architecture and standards for flexible hardware and facilities, and context-aware robots. It is expected that these topics will be important for triggering more interactions within upcoming smart cities.

5. DISCUSSIONS

The current study offers insights for both practitioners and researchers in interdisciplinary areas, such as smart cities. To be more elaborate, this study makes several contributions to discussions on developing research agendas and exploiting interdisciplinary research. This study attempts to derive the emergence of research issues in smart cities. In this process, I also propose a methodological framework that can provide insights for smart city research. In addition, this study provides potential policy implications for researchers and practitioners in smart cities. Thus, the findings correspond to recent calls for further research on future designs. This study considers and leverages the latent trends in academia that provide external innovative ideas to facilitate the development of interdisciplinary areas.

First, there are many widely used techniques for bibliometric analysis, but they are somewhat fragmented to comprehensively understand changes in newly emerging interdisciplinary areas. For example, one technique can discover a topic, but it is difficult to analyze its temporal changes. In fact, there are currently many interdisciplinary areas that have attracted great interest from researchers and practitioners and require a long time for their emergence. Therefore, their temporal trends are important, but the fragmented use of each bibliometric technique might be limited in dealing with this perspective. Here, the contribution of this study lies in the provision of a systematic and comprehensive approach and empirical findings to identify the emerging interdisciplinary areas, such as smart cities.

Second, this study attempts to utilize the topic for their convergence, whereas some previous studies mostly focus on the citations or co-occurrences of classification codes for tracking the convergence between areas. Citations are a good measure of knowledge flow, but they take a long time to be made. While it might lack an intuitive interpretation for citation-based research, this study could contribute by directly analyzing and predicting the link between topics.

Third, this study empirically deploys the proposed approach to one of the representative interdisciplinary areas of a smart city. In particular, smart cities are technology-driven with diverse areas; therefore, the technological convergence aspect fits well with the research scope. While topics are continuously evolving, predicting their links could lead to the emergence of new areas. Grafting technology convergence to understand interdisciplinary areas could play an important role. Furthermore, the prediction of topic convergence could be significant for the growth of interdisciplinary areas in several ways.

In summary, this study focuses on a comprehensive and systematic approach to bibliometric features, where texts and temporal aspects are considered significantly. The contribution of this study relies on the systemic and integrated approach to newly emerging topics in the interdisciplinary area, that is, the smart city, although the findings and implications are somewhat outdated. In addition, such findings can be utilized for topic-link predictions. The proposed approach is also expected to be applied to different interdisciplinary areas. Eventually, this study could lead to a deeper understanding of interdisciplinary areas and effectively utilize the findings in a convenient way.

However, this study is potentially limited in that it only considers academic perspectives on the targeted areas, and it covered limited investigation of network changes that SIENA provides. As a result, findings of this paper provide the emerging convergences on context aware agent or robots, the smart transportation, and the smart grid. Since those might be somewhat abstract, more focused examinations and industry specific interpretations are still necessary. In addition, the proposed method smooths the temporal networks, which might include the expected issues or unexpected issues. If there is any sudden issue, which could be influential, in the certain network, the current effort might be difficult to particularly focus on that unexpectedness. Those limitations could be further made up in the following studies.

6. CONCLUSION

There has been an increasing interest in research on smart cities for innovative product and service development. Based on a quantitative approach, this study extracted emerging research issues and determined their likeliness to emerge and evolve. Consequently, this study applied LDA to identify emerging topics in smart cities. Temporal analysis of the topic networks was consecutively applied to deeply understand the evolution of research in smart cities. Findings from this study suggest that convergences between smart transportation and smart grids are likely to appear. Such findings could contribute toward exploiting emerging topics and their convergence in smart cities for sustainable development. Findings indicate that the research in smart cities is currently weak to external changes. Exploiting open ecosystems can be carefully approached to pursue the sustainable advancement of smart cities. This research mainly considers the newly emerging interdisciplinary area, which is at an establishment stage, both retrospectively and prospectively. Based on this understanding, this study further attempts to deploy link prediction on topics and their convergences in an interdisciplinary area, that is, a smart city. Furthermore, this study contributes to the systematic methodological deployment for treating texts, and it also shows that such a comprehensive approach could function well with new interdisciplinary areas. although the findings might lack impressive aspects. In addition, findings on the hot topics discovered and research evolution provide a basis for future research areas. That is, the proposed methodology and results might provide a meta-level design for new research models in interdisciplinary areas. Despite some limitations of this paper, it is expected that this paper could contribute towards providing empirical data, implying that the proposed method can be appropriately applied. This can broaden research perspectives and contribute to the development of emerging industries and economic growth for sustainable development. Consequently, the findings are useful for researchers, practitioners, and policymakers, to enhance their engagement in developing better smart cities.

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