Dynamic analysis on public concerns in Hong Kong-Zhuhai-Macao Bridge: An integrated topic and sentiment modeling approach

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ABSTRACT

Public concerns exert far-reaching influence on various phases of megaprojects, requiring the decision-makers to achieve dynamic analysis in the aspects of identification, measurement, and management. The study proposes an integrated topic and sentiment modeling approach to analyze the dynamics of public concerns from unstructured project documents. First, the Topic over time model is adopted to identify the public concerns and trace the trend of public popularity on the concerns. Second, the Bert based sentiment model is developed to reveal the trend of public sentiment towards each public concern. Finally, a mirror "N" strategic

model is proposed considering the trend of public popularity and sentiment, together with the classical public participation strategies: collaboration, consultation, involvement, and information. With the 1748 official documents from the Hong Kong – Zhuhai – Macao Bridge, the proposed method is validated. As a result, sixteen public concerns and their levels of popularity trends are identified in sixteen years of project duration by the TOT model. The volatile and mild public sentiment changes are tracked in the timeline by the Bert based sentiment model. The recommendation of management strategies derived from the mirror "N" strategic model is summarized on public concerns in three project phases: planning, construction, and handover. The dynamic data-driven method bridges the knowledge domains of public participation studies and text-mining technologies for better megaproject management.

INTRODUCTIONS

Public concerns reflect the legitimate demand of the people, which significantly affect the development of megaprojects in various stages (Lin et al., 2018). In the planning stage, public concerns may push decision-makers to suspend or even cancel projects due to uncertainties regarding environmental and economic interests, which frequently occur in energy and highway projects (Wu et al., 2019, Zafar et al., 2019). Public concerns urge involved organizations to implement corporate social responsibility in the construction stage (Lin et al., 2018) and highly influence the policy of operational arrangements in the handover stage (Xue et al., 2020c). Therefore, public concern analysis is crucial in the dynamic environment of megaprojects to alert for risks and provide management strategies. However, previous small and unrepresentative samples collected in a given timepoint from traditional survey methods cannot trace the continuous changes of public concerns (Vandeweerdt et al., 2016). To address this limitation, official project documents with time-stamped information can provide reliable dataset to undertake dynamic analysis of public concerns in long-term project duration.

As an efficient method to analyze public concerns from a large volume of project documents, the opinion mining technique is developed as a branch of text-mining approaches in the domain of computer science (Hemmatian and Sohrabi, 2019). This technique has two critical parts. One is the topic modeling approach, which is useful to detect the core concepts of public concerns from the sea of the text (Yao et al., 2016). The other is the sentiment modeling approach, which evaluates the attitudes of public concerns in the text (Tang et al., 2017). Among topic models, Topic Over Time (TOT) has an advantage of reflecting the dynamic concept patterns, which is emphasized in dynamic analysis (Wang and Mccallum, 2006). Among sentiment models, BERT has been proven to have state-of-art accuracy to judge the level of positive or negative attitudes in the text (Devlin et al., 2018). By learning the text in unstructured project documents, the integration of topic and sentiment modeling approaches enables the understanding of public concerns and public attitude toward each concern in the timeline.

The Hong Kong–Zhuhai–Macao Bridge (HZMB) is the world's longest cross-sea bridge, which connects three major cities in Southern China with different political systems (Xue et al., 2020c). Compared with the definition of megaprojects in which the budget is over 1 billion United States dollars (USD) (Flyvbjerg, 2014), HZMB costs 18 billion USD in total, with the severe delay and cost overrun due to the conflicts caused by public concerns. As a mega cross-boundary infrastructure connecting three regions under the unique political system "One Country, Two Systems," HZMB provides an opportunity to learn the dynamics under the high complexity of public concerns in the project duration (Xue et al., 2020a).

In this study, we aim to develop a method to realize the dynamic analysis of public concerns in megaprojects from unstructured project documents, finally revealing the dynamic patterns and providing a management guide. First, the TOT model is used to analyze the official project documents on the HZMB from the planning and construction to the handover stage. As a result, we detect the critical public concerns and

explore the popularity trend of each concern annually. Second, the BERT-based sentiment model is developed to measure the public attitude towards each concern in the timeline. Finally, combining the results of the TOT and BERT-based sentiment models, we develop a dynamic strategic model to provide a management guide on public concerns in megaprojects validated by the case of HZMB.

BACKGROUNDS

Public concerns analysis in megaprojects

Public concerns exert considerable influence on the success of megaprojects (Wang et al., 2016). Appropriate response to public concerns gains public support whereas failure management of public concerns escalates to public opposition (Breukers and Upham, 2015, Li et al., 2015). Given that megaprojects have long-term duration (Mok et al., 2015), public concerns vary in different project phases, calling for a dynamic analytical tool in research (Xue et al., 2020a). Unfortunately, dynamic analysis of public concerns in megaprojects is lacking due to the limitations in the aspects of identification, evaluation tools, and management strategies.

In public concern identification, traditional survey sampling technique is still the dominant approach to explore critical public concerns (Valentin et al., 2018, Schuman and Scott, 1987). However, the survey data collected in a given project time is insufficient to support dynamic analysis (Vandeweerdt et al., 2016). To address this limitation, previous studies have traced public concerns through online opinions, which provide timestamped information (Bertot et al., 2012). Nevertheless, online public opinions have been argued to have inherent deficiencies. First, netizens are mainly from the younger generation, and thus results may lead to biased public concerns (Xue et al., 2020b). Online information highlights several hotspots receiving wide attention among netizens; however, public concerns that do not dominate media headlines may leave out although they exist among specific public groups (e.g. senior residents, less educated citizens, manual

89 workers). Second, online information is scattered and not directly relevant to the project, which may increase
90 the difficulties on identifying public concerns (Jiang et al., 2016b). The parliament is a place to express public
91 concerns on the critical issues in society, and thus the documents of council meetings provide a reliable and
92 official data source (Vandeweerdt et al., 2016). Before each bill vote regarding the project, debates are
93 frequently organized and are recorded in council documents, which therefore present a comprehensive view
94 of public concerns in every aspect of megaprojects in the timeline (Xue et al., 2020a, Xue et al., 2020c).

95 Apart from using the Likert scale to measure the criticalness of public concerns using questionnaire
96 survey (Li et al., 2015, Yu and Leung, 2018, Leung et al., 2013), data-driven analytical approaches have been
97 adopted for public concern evaluation with large datasets. Topic modeling is used to explore the critical
98 concepts of public concerns in project-related texts (Jiang et al., 2016c, Jiang et al., 2016d). Sentiment analysis
99 is used to evaluate the public attitude in social media posts over the project duration (Tang et al., 2017, Jiang
100 et al., 2016a). However, each technique is commonly used separately. In other words, no existing modeling
101 approach integrates the function of two techniques that assesses public sentiment toward each identified public
102 concern in the various stages of megaprojects.

103 Effective public participation is considered as an essence to manage public concerns. Public
104 participation is first proposed by Arnstein (1969) as a ladder to realize citizen involvement in the decision-
105 making of construction projects. Based on the level of public engagement, public participation can be divided
106 into four strategies: collaboration, involvement, consultation, and information (Jami and Walsh, 2014). In the
107 low engagement level, information strategy only conveys project information to the public (Brown et al.,
108 2018). In the medium engagement level, involvement and consultation strategies provide opportunities for the
109 public to have formal communications with decision-makers (Boyer et al., 2015, Fishkin et al., 2000).
110 However, the final decisions are still made by officials. In the high engagement level, the collaboration strategy

111 highlights citizen power and partnership to build a joint decision-making between decision-makers and the
112 public (Newman et al., 2004). Although management strategies are proposed and practiced in construction
113 projects (Leung et al., 2014, Leung et al., 2013), the proper mechanism to determine the use of strategies in
114 the dynamic environment of megaprojects is still lacking. Therefore, establishing a strategic model for public
115 concerns according to the measurement result of critical public topics and changeable public sentiment in the
116 long-term project duration is promising.

117 **Topic and Sentiment Modeling Approaches**

118 Topic models are used to automatically cluster the critical topics from the text, which are developed
119 from probabilistic graphical models (Koller and Friedman, 2009). Various classical topic models in computer
120 science include PLSA, LDA, and TOT models (Yao et al., 2016). PLSA and LDA are static models with the
121 limitation of detecting dynamic text patterns (Hofmann, 2001, Blei et al., 2003), while the TOT is a dynamic
122 model that well addresses the incapability of capturing chronological features in static topic models (Yao et
123 al., 2016). In construction management, static topic models like LDA model undertake text-mining tasks to
124 reveal public opinions in previous studies (Jiang et al., 2016b). However, the chronological patterns of public
125 concerns are unexplored in the dynamic project environment due to the inherent deficiency of static topic
126 models. The TOT model is developed by a full consideration of token co-occurrence and timestamped corpus,
127 thus reflecting relationships between the topic, word, and timestamp in a continuous distribution over time
128 (Wang and Mccallum, 2006). TOT has received popularity in the dynamic text-mining tasks since its birth
129 (Wang and Mccallum, 2006). To validate the topic models, Mimno et al. (2011) devised a semantic coherence
130 score. The score represents the word co-occurrence level between the high-probability feature words assigned
131 to each latent topic. The validation method has replaced traditional human judgment to select the best-fit topic
132 model for the specific task.

Sentiment analysis is useful to understand public opinion by evaluating the corpus with sentiment values (Tang et al., 2017). Classical sentiment modeling approaches in computer science include the lexicon-based approach and machine learning techniques (Gui et al., 2017, Li et al., 2018, Zhao et al., 2020). In the lexicon-based approach, the sentiment value of each sentence is assessed by a group of attitudinal, degree, and negation words (Cao et al., 2013). Therefore, an advance word lexicon of a specific field is essential for sentiment assessment (Jiang et al., 2016b, Jiang et al., 2016a), a necessity that leads to two bottlenecks. First, the field of megaprojects has no word lexicon. Second, the word-based lexicon method does not comprehensively consider the information of the entire sentence, hindering the accuracy of sentiment analysis (Hemmatian and Sohrabi, 2019). Machine learning techniques successfully make up for the above deficiencies by assessing the content sentiment with contextual information through the deep learning of the text (Hemmatian and Sohrabi, 2019). The latest BERT model provides state-of-the-art performance on sentiment analysis compared with the previous Word2Vec and GloVe machine learning techniques (Li et al., 2019). The BERT model can capture semantic dependencies in the content and improve the prediction performance using powerful embedding layers pre-trained with a huge dataset (Rogers et al., 2020). The BERT workflow includes two steps. First, pre-training finalizes the word embedding through masked language modeling (MLM) and next sentence prediction (NSP). MLM and NSP help BERT to understand the contextual information of the text. Second, fine-tuning adds sentiment-task layers to the final word embedding layers to complete the sentiment scoring (Li et al., 2019).

METHODS

Research Framework

As Figure 1 shows, the research framework comprises three steps, including public concern identification, measurement, and management. First, after collecting the project-related text files in an official

source, public concern identification is conducted by the TOT topic model to reveal critical concerns and trace their changes of public popularity in the timeline from the commencement to the completion of the Hong Kong-Zhuhai-Macao Bridge (HZMB) project. Second, a BERT based sentiment model is developed to measure the trend of public sentiment towards each public concern, which shows the variations of public attitude in continuous timepoints of HZMB. Third, a "Mirror N" strategic model is proposed to manage public concerns in various phases of HZMB, with the consideration of the trend of popularity and sentiment towards the public concerns. The proposed framework with the integration of three models could be used to assist decision-makers in managing public concerns of megaprojects, by learning knowledge from the unstructured project documents.

<**Figure 1. Research framework of dynamic analysis on public concerns**>

Data Collection

As stated in the section of background, the parliament documents record the broad topics of public concerns in the timeline regarding the megaprojects. Besides, it is accessible for the public to obtain parliament documents in most democratic societies worldwide. In the study, the project documents of HZMB were collected by an online archive of the Legislative Council in Hong Kong where the project is located, with searching terms as "Hong Kong-Zhuhai-Macao Bridge" or "HZMB." Then, data cleaning was processed to remove the irrelevant text from the raw dataset. To validate the topic relevance of collected data, two researchers were invited to examine whether the project documents were on the issues of public concerns or not by fast browsing each text file's content independently, the method of which was also echoed by Tang et al. (2017). Only the mutual accepted documents were finally included in the dataset for analysis. Finally, 1748 official documents on HZMB between 2003 and 2018 were collected for further dynamic analysis.

Topic Over Time Model

Topic Over Time model (TOT) was developed based on the traditional basic Latent Dirichlet Allocation model (LDA). Different the traditional LDA, TOT simultaneously models the content and time information of the text. Specifically, TOT utilizes the timestamps of documents, which reflects topics' time information, to analyze topic distributions of documents. The graphical model of TOT is shown in Figure 2. First, a multinomial distribution $\emptyset_Z$, which follows a prior Dirichlet distribution β, is drawn for each topic z. Second, we draw a $\emptyset_d$ which follows multinomial distribution from a prior α which follows Dirichlet distribution for each document d. Third, for each word in a document d, where, we draw a z_{di} which follows the multinomial $\emptyset_d$, a word w_{di} which follows multinomial distribution $\emptyset_{z_{di}}$ and a timestamp t_{di} which follows Beta distribution $\varphi_{z_{di}}$. N_d is the total count of words in a document d and i represents the *i*-th word in a document d.

In this study, the hyper-parameter α and β were valued as $\alpha = 50/\mathrm{T}$ and $\beta = 0.1$ respectively based on previous work Wang and Mccallum (2006). Besides, in order to obtain better text quality, we preprocessed the raw text through TF-IDF since it can filter unimportant words.

<**Figure 2. Graphical model of TOT**>

As stated in the section of background, the semantic coherence score was designed to examine the validity of the TOT model. Following the rule of the coherence score, the co-occurrence of the top 15 words that have the highest correlation probabilities under each specific topic derived from the TOT model is calculated (Mimno et al., 2011). The higher co-occurrence rate stands for the closer semantic relationship among the clustered words, indicating the better result of topic clustering by the TOT model. The formula is as follows.

$$C\left(Z; V^{(z)}\right) = \sum_{m=2}^{15} \sum_{l=1}^{m-1} log \frac{D\left(v_m^{(z)}, v_l^{(z)}\right) + 1}{D(v_l^{(z)})}$$

Where the $V^{(z)}$ represents the top 15 highest corelated words under the topic z, and $D\left(v_m^{(z)}, v_l^{(z)}\right)$ means the frequency of co-occurrence between every two words in the $V^{(z)}$. The score value $C\left(Z; V^{(z)}\right)$ closer to zero indicates the better clustering results from the TOT model.

BERT based sentiment model

The BERT based sentiment model was composed of two parts, as Figure 3 shows. The first part is the BERT embedding layer, which transforms each word-token from the official project documents to the numerical representation by considering the contextual information of the paragraph. The second part is the classification modular for the sentiment classification based on the output from the BERT embedding layer, after which it is obtained the sentiment score for each paragraph in the documents.

In the first part, the input word-token sequence is packed in combinations of the token-embedding, position embedding, and segment embedding. Then, the input embedded features are refined by L transformer layers to H_L, which is considered as the contextual representations of the input word-token sequence and ready to be used for the sentiment classification task. In the second part, we first add a fully connected layer on top of the BERT output layer, which is used to transform the output embedding to a real-valued vector whose length is the same as the number of sentiment class label, then a softmax layer is adopted to make the prediction. With the softmax activation function, the prediction results are finalized from the range of zero to ten, where the score zero means the extremely negative attitude, and the score ten stands for a strong positive attitude.

$$P(y_t|x_t) = softmax(W_0 h_t^L + b_0)$$

Where W_0 represents the learnable parameters in the fully connected layer. b_0 is the prediction error.

In this study, the pre-trained “bert-based-uncased” model was used, which consists of 12 transformer layers with 768 dimensions of the representation vector (Li et al., 2019). Based on the parameter setting of previous BERT studies, the learning rate and batch size were set as 2e-5 and 16, respectively (Li et al., 2019). The

model was trained up to 1500 steps (Li et al., 2019).

With the BERT based sentiment model, the sentiment score of each paragraph in the text is obtained. Then, it is essential to assess the correlation between the topic and the paragraph, so as to calculate the sentiment score under a specific time of a topic by calculating the average sentiment score of paragraphs which have high relevant about the topic.

To measure the relevant $N(p,Z)$ between a paragraph p with a topic Z, we use feature words V and the probability of relation $prob(Z,V)$, which both getting from TOT model to do the phrase match on a paragraph. The 15 feature words with the highest correlation are first subjected to sum normalization, and the sum of probability of feature words appearing in the paragraph is the correlation between the given paragraph and topic.

$$0 < i < j, \qquad if\ prob(Z_i, V_i) > prob(Z_i, V_j)$$

$$N(p, Z_i) = \frac{\sum_{w=1}^{15} prob(Z_i, V_w) * 1_p(V_w)}{\sum_{w=1}^{15} prob(Z_i, V_w)}$$

After getting the correlation of all topics to a paragraph p_k, the T topics with the highest correlation are considered as highly relevant to the paragraph. Let A_{p_k} be the set of topics with high relevant with paragraph p_k.

$$0 < i < j, \qquad if\ N(p_k, Z_i) > N(p_k, Z_j)$$

$$A_{p_k} = \{ Z_i \mid i \leq T \}$$

Finally, given topic Z and timestamp Y, we calculate the sentiment score $sentiment(Z,Y)$ by averaging sentiment score of all paragraph p_i with topic Z belong to topic set A_{p_i}. The sentiment score $M(p_i)$ of paragraph p is generated by the BERT model. Let $C(Y)$ be the number of paragraphs in the timestamp Y.

241 $$sentiment(Y,Z) = \frac{\sum_i^{C(Y)} M(p_i) * 1_{A_{p_i}}(Z)}{\sum_i^{C(Y)} 1 * 1_{A_{p_i}}(Z)}$$

242 **<Figure 3. The BERT based sentiment model>**

243 **Mirror N strategic model**

244 A strategic model (Figure 4) is proposed for managing public concerns in various phases of
245 megaprojects. The vertical axis stands for the public popularity of the topics assessed by the TOT topic model,
246 the value of which is the mean of correlation probabilities between the timestamped documents and the
247 identified public concerns. The horizontal axis shows the public sentiment of the topics evaluated by the Bert
248 based sentiment model, the value of which is the average sentiment score for each public concern. The vertical
249 and horizontal axis form the strategic map with four zones, which is divided by the average values of each
250 vertical and horizontal axis.

251 Since the lower sentiment score indicates the less satisfactory of corresponding concerns from the
252 public, the decision-makers focus on addressing the public concerns with below-average sentiment score on
253 the map primarily. Therefore, the topics distributed in the upper left of the figure are the most important topics
254 with high popularity and low sentiment score, while the topics distributed in the right bottom of the graph are
255 the least essential topics with limited popularity and high sentiment score. Based on the importance of public
256 concerns for decision-makers, the managerial priority starts from Zone One, passing by Zone Two and Three,
257 finally ending at Zone Four. The managerial path is like a mirror image of the letter “N.”

258 In combination with the existing public participation techniques, it is provided the management
259 strategies for public concerns in each zone on the map, considering both the importance of popularity and
260 sentiment among the public. In Zone One, the collaboration strategy is suggested towards the concerns with
261 the less satisfactory sentiment but receiving the wide public attention. The collaboration strategy encourages

high-level public participation in the joint decision-making process related to public concern, through the citizen advisory committee and participatory decision making (Newman et al., 2004, Wang, 2001, Xie et al., 2014). In Zone Two, since the low sentiment comments exist in the narrow scope of the public, the consultation through focus group meetings would be an economical approach to solve the concerns from the targeted public group in a timely manner, in avoid to the expansion of public popularity (Norton and Hughes, 2017, Hall and Lazarus, 2015). In Zone Three, even though the public is satisfied with the relevant concern, the wide public popularity still calls for the public involvement strategy, including the workshops and deliberative polling. The strategy highlights the criticalness of interactive activities between decision-makers and the public in the negotiation throughout the project duration, which is useful to prevent the reverse of positive public sentiment (Shan and Yai, 2011, Jami and Walsh, 2014). In Zone four, as the public popularity is limited with the high sentiment score, the decision-makers require smooth access for communicating with the public regarding their concerns. Therefore, the inform strategy is essential to convey the project policy to the public and collect their feedback for the continuous improvement in addressing the public concerns (Jami and Walsh, 2014).

<Figure 4. Mirror N Strategic Model for managing public concerns>

RESULTS

Critical Public Concerns

According to sensitivity analysis of semantic coherence scores listed in Figure 5, the TOT model with 16 identified topics has the closest value to zero, indicating it is the best-fit model which the results are most valuable to make further interpretation. As Figure 6&7 show, each identified topic is presented by 15 feature words with highest correlation probabilities. The feature words are used to interpret the concept of the corresponding topic, which is echoed by Jiang et al. (2016d) in the similar study. For instance, the highest relevant feature word of topic #1 is “commun”, which is the word stem of “community”. The second and sixth

284 rank of feature words are “western” and “tuenmun”, respectively, representing the location of communities is
285 near the construction sites of HZMB. The other words “infrastructure”, “demand”, “develop”, and “transport”
286 reflect the demand of local communities to develop the transport infrastructure with the construction of
287 HZMB. Therefore, the concept of topic #1 is “local community”. Similarly, the concepts of other 15 identified
288 topics are interpreted by feature words in supplemental document S1.

289 As Figure 6&7 show, the 16 identified public concerns cover the wide-range issues, including the
290 government cooperation (#2), environmental impacts (#3), commercial development (#15), alignment options
291 (#0), financing arrangements (#11), operational arrangements (#4&5&6&8), design (#13), and construction
292 (#12), even radiating to the sustainable development of local towns (#1&10), infrastructures (#9), and
293 economy (#7&14).

294 **<Figure 5. Results of TOT modeling validity test>**

295 **<Figure 6&7. The concept of each topic with top 15 correlated feature words>**

296 **<Figure 8. Popularity Trend of Public Concerns in HZMB>**

297 **Popularity Trend of Public Concerns**

298 With the TOT topic model, the popularity trend of public concerns was traced in the timeline from the
299 beginning to the completion of HZMB. The popularity trend is shown in Figure 8. The figure shows the annual
300 changes of correlation probabilities between documents and identified public concerns, which represents the
301 chronological pattern of popularity for each public concern in the project duration.

302 The popularity trend of public concerns could be categorized by three levels. First, the governmental
303 cooperation (#2) dominates the top popularity level with the maximum correlation probability value reaching
304 at almost 1.0 in the mid-term of HZMB. Second, there are four public concerns regarding the aspects of
305 ecological protection (#3), local link roads (#9), financial arrangements (#11), and business advancement

306 planning(#15), which receive the medium popularity level with maximum correlation probability value at 0.4.
307 Third, another eleven public concerns concerning wide topics with the maximum correlation probability value
308 at 0.1 are recognized as the low popularity concerns.

309 **Sentiment Trend of Public Concerns**

310 With the BERT based sentiment model, the sentiment trend of public concerns was revealed, which
311 indicates the dynamic patterns of public sentiment towards each detected concern. The sentiment trend was
312 shown in Figure 9. The figure presents the changes of average sentiment score in each year, representing the
313 annual public satisfactory level on the concerns throughout the project duration.

314 The sentiment trend of public concerns could be grouped by two categories based on the range of
315 changeable sentiment scores in the project duration of HZMB. The first group consists of the issues on
316 cooperation across governments (#2), environment (#3), finance (#11), and commercial development (#15),
317 with the larger scale of sentiment score ranging from 4.5 to 6.0, showing the volatile public sentiment in
318 various project phases. The second group includes other twelve public concerns ranged from 5.2 to 5.6,
319 illustrating the more stable public sentiment in the project duration.

320 **<Figure 9. Sentiment Trend of Public Concerns in HZMB>**

321 **Strategic Map of Public Concerns**

322 With the strategic model, the public concerns are depicted in the strategic map (Figure 10) with four
323 zones, considering the trend of public popularity and sentiment. In the study, the dynamic management
324 strategies are discussed, followed by the "Mirror N" strategic model in three project phases of HZMB:
325 planning, construction, and handover, covering 16 years of project history in total.

326 **<Figure 10. Strategic Map of Public Concerns in HZMB>**

327 **DISCUSSIONS**

Dynamic popularity of public concerns

Public concerns with high popularity

Cooperation across governments (#2) received the highest public popularity between 2008 and 2014, which includes the late planning and early construction phases (see Fig. 8). The period covers a series of milestones in the decision-making process of HZMB, including the assessment of the project feasibility report, voting for the project bill in the National people's congress, and the juridical review on environmental impact assessment. Each milestone is highly related to the smooth project commencement, which is required for governmental collaborations between three regional administrations since HZMB is a joint funded project connecting three cities with different political systems. Therefore, the cooperation level among the three regional governments attracted the highest public attention during the decision-making phase.

Public concerns with medium popularity

Apart from the most popular concern, four additional public concerns received medium popularity (#3,9,11,15), which are also essential to reflect the critical public attention in HZMB. Unlike the above top concern with one peak in the decision-making phase, all the medium popularity concerns acquired concentrated public focus twice in the project duration (see Fig. 8). The first hotspot occurred when the issue was initially proposed for negotiation between public and decision-makers in the planning phase, and the second hotspot erupted as criticism followed due to the less satisfactory performance when the relevant issue was carried out in the construction phase. For instance, environmental issues (#3) first raised broad public concerns on the advocacy for protection measures of marine ecology in the planning phase. Unfortunately, the local community still appealed to the higher court due to their disappointment of the final environmental impact assessment report, thus raising the public concerns again during the construction phase. A similar case occurred on the issue of local connectivity (#9). In the early planning phase, the development of the local road

system in the connecting areas of HZMB received an in-depth public discussion, as the public worried that the existing transport infrastructure would be overloaded with the increasing traffic volume brought by HZMB. These public uncertainties resurfaced in the late construction phase when HZMB came close to operating because at that time, the local links that were under construction faced severe project delays. The imbalanced development between local connectivity and HZMB stimulated doubts on the potential traffic problems among the public, leading to the second popularity peak.

Public concerns with low popularity

Although 11 public concerns with low-level popularity did not receive full public attention in the project (see Fig.8), these cover a wide range of issues regarding HZMB such as alignment options (#0), operational arrangements (#4, 5, 6, and 8), design (#13) and construction (#12), even radiating to the sustainable development of industries (#7), regional economy (#14), local towns (#10), and communities (#1). Most low-level public concerns received two peaks at the start and end of HZMB, respectively, which indicates diverse public concerns concentrated at two polar time points of the project.

Dynamic sentiment of public concerns

Public concerns with volatile sentiment

As Figure 9 shows, the public concerns with volatile sentiment can be traced in various phases of HZMB. In the planning phase, public concerns on financial arrangements (#11) received dramatic changes of sentiment scores, triggered by the expectations on the maximization of local economic benefits among the public in Hong Kong. Each proposed financial mode led to the volatile sentiment change due to the subsequent criticism of its shortages. Concerns on the increased toll level under the initial Build-Operate-Transfer mode caused the plunge of the sentiment score in 2005. Subsequently, complaints about Hong Kong government undertaking the largest share in the project loan pulled public sentiment down again in 2008 when the National People's

372 Congress of China passed the final bank-loan financial mode of HZMB.

373 When the construction works commenced, public concerns on cooperation across governments (#2) and
374 commercial development (#15) experienced a significant decrease in sentiment scores in the early and middle
375 construction phases. The cooperation across governments (#2) faced public doubts due to the imbalanced
376 development progress of HZMB. Construction works were smoothly initiated in late 2009 on the Zhuhai and
377 Macao sides. However, the Hong Kong side had a severe project delay because of the juridical review on
378 environmental impact assessment. The public was concerned that pressure from the mainland government for
379 the expedition of HZMB would interfere with the environmental assessment. Meanwhile, the postponement
380 of commercial development (#15) on HZMB local facilities pulled the public sentiment downward as the
381 economic benefits were the primary concern among residents in neighboring areas. The continuous barriers
382 of structure design, land use alteration, and technical difficulties raised public doubts on whether the promised
383 economic profits brought by HZMB would be realized. The decreased sentiment had a significant negative
384 influence on public support amid the project execution.

385 When HZMB was close to completion, sentiment scores on environmental issues (#3) declined from the late
386 construction phase to the handover phase. Escalated concerns regarding air and ocean pollution due to the
387 forthcoming operation of HZMB caused the sharp decrease of public sentiment. The public conveyed concerns
388 on the surge of gas emission and fuel leak from vehicles that would severely damage the environment of local
389 connective areas.

390 ***Public concerns with mild sentiment***

391 Apart from the four public concerns with volatile sentiments, the other 12 have a mild sentiment trend ranging
392 between 5.2–5.6, which indicates that the public has a mild attitude toward the issues. However, two
393 interesting patterns are captured in the Figure 9. First, the public sentiment declined when HZMB was

anticipated to be overdue in 2016. The public dissatisfaction was reflected by sentiment scores on construction (#12) and design (#13) issues, which fell to their lowest in 2015 and 2016. As project delays stimulate stakeholder conflicts in megaprojects, the evidence further indicates that the postponement of completion also downgrades the public impressions of the project. Second, the public complaints turned to the transport arrangements and synchronized development of the local economy in the handover phase. As Figure 9 shows, issues on transport operation (#5, 8) and the urban economy (#10, 14) received reduced public satisfaction in 2018 when the project was due to operate. Thus, decision-makers can focus more on the operation and urban development issues to gain public support at the late project phase.

Dynamic management strategies for public concerns

Planning Phase

As Figure 10 shows, the planning phase for Zone One has two most critical public concerns: cooperation across the regional governments (#2) and local connectivity (#9). The political collaboration is crucial for the success of cross-boundary projects, which is echoed by Xue et al. (2020c). In HZMB, the public focused on whether the coordination of three regional governments faced intense pressures from national central governments when making important decisions, such as alignment options, financial arrangements, and environmental design. Therefore, collaboration is essential between decision-makers and the public to remove the latter's concerns and gain their support. The citizen advisory committee is recommended to invite the public to participate in the governmental negotiation to maintain information transparency (Xie et al., 2014).

In Zone Two, the concerns on financial arrangements (#11), alignment options (#0), and local traffic conditions (#6, 8) receive a low public sentiment score among the public. The concerns came from specific public groups, and thus did not lead to widespread public attention. For instance, alignment (#0) and local traffic (#6&8) issues were the core concerns of residents in the connective areas of HZMB whereas the financial issue (#11)

was discussed among public intellectual representatives in civic groups. As the targeted public group is relatively small and fixed, the consultation strategy is quite suitable to hold focus group meetings on solutions to address the concerns (Rowe and Frewer, 2005).

In Zone Three, environmental (#3) and commercial development (#15) issues receive the full public attention with positive sentiment. The public actively provided various suggestions regarding these two items in the planning phase. For environmental issues (#3), the people looked forward to the strict protection measures for endangered Chinese White Dolphins in the design and construction works of HZMB. For commercial development (#15), the public hoped for the government to expedite the proposed "bridgehead economy" and develop a large number of business and recreational facilities around HZMB local links. Given that these two issues are highly relevant to the core interests of the public who desire to have a sustainable and prosperous future, the involvement strategy is required to sustain their interactive access to the decision-makers. Workshops and public forums can be used to continually listen to comprehensive public opinions and maintain positive public impressions by actively responding to the concerns (Wang, 2001).

Zone Four has eight public concerns, which account for half of the total identified concerns. The phenomenon implicates that most issues do not received much public attention given that the project is in the initial phase. Thus, the information strategy can notify the public of the latest progress of these eight issues.

Construction Phase

Based on the results in Figure 10, financial issues (#11) are the top public concern in the construction phase, which is the only concern in Zone One. The severe cost overrun in HZMB caused widespread public attention, leading to public doubts on whether this project would be a "white elephant" (luxury but useless). Given that the megaproject has a vast investment scale that requires a long-term payback period, the public is much sensitive to cost-overruns that may increase the financial burden for future urban development. In HZMB, the

delay of construction commencement and completion triggered several rounds of extra payment bills, causing public concerns on the economic benefits of HZMB. Public opposition exerted substantial pressure on each vote of additional project payment bill in the legislative council. To ensure public support for extra budgets given the financial challenges, collaboration is urgently used to involve the public representatives in the joint decision-making on assessing and issuing additional funds to continue moving the project at a smooth pace.

Zone Two includes a variety of public concerns, including local industry (#7), transport arrangement (#5, 8), urban economy (#10, 14), construction (#12), and design (#13). The commencement of construction works led to harsh public comments in a wide range of social, economic, and technical issues around HZMB. Fortunately, each concern was discussed within the limited number of particular public groups, which can be addressed using the consultation strategy. For instance, the operation of cross-boundary traffic (#5) received the lowest sentiment score in Zone Two. Business travelers and logistic companies were the dominant groups to convey concerns on whether the transport arrangement can match their expectations of a convenient and fast journey between Hong Kong, Zhuhai, and Macao. Therefore, focus group meetings between decision-makers and targeted public groups are essential to negotiate for the optimal operational policies in the construction phase (Xie et al., 2019).

In Zone Three, the governmental cooperation (#2) issue continues to receive the highest public popularity in the construction phase compared with the planning phase. However, the issue's sentiment score increased, indicating an improved public satisfaction. Despite the sharp sentiment decrease due to the conflicts on environmental impact assessment, the HZMB advanced steadily with the strong will of governments between Hong Kong, Zhuhai, and Macao, which buoyed the public confidence regarding the project success. Unlike in the planning phase wherein the governments face many crucial decision-making moments, the construction phase focuses more on project execution. Therefore, reasonably, public concerns on management of

governmental issues switches from the collaboration strategy that emphasizes the joint decision-making between decision-makers and the public in the planning phase to the involvement strategy that calls for frequent interactive communication on the problems and challenges occurring in the construction phase.

Zone four only has three public concerns. Among these, local community (#1) seems to be a safety issue with low public popularity but high public sentiment. However, given that this issue surged in public popularity in the subsequent handover phase, the proactive information strategy is recommended to establish a positive project image through more experiential activities, such as public exhibitions and open-site visits (Jami and Walsh, 2014). The content of public information actions can focus on how the project benefits the life quality of local residents.

Handover Phase

As Figure 10 shows, transport arrangement (#5, 8) and construction (#12, 13) issues are the most critical public concerns in the handover phase. As the HZMB came close to operation, the transport arrangements (#5, 8) became the hot topic among the public, with the different traffic rules among the three regions gaining public complaints. The primary issue was the driving tradition that vehicles are left-driving in Hong Kong and Macao but right-driving in the mainland. The adaptation of traffic regulations in different regions increased the inconvenience level of travelers, leading to the decline of public sentiment. Therefore, the collaboration strategy is essential to form a public advisory committee to properly discuss the incorporation of various traffic regulations into the unified transport arrangements (Xie et al., 2014). The construction issues (#12, 13) are seldom mentioned to become the critical public concern in this phase. As HZMB comes close to operation, the performance of the construction and design attracts considerable public concerns, which brings substantial pressure for all internal project stakeholders (contractors, sub-contractors, suppliers, consultants) and governments. For instance, the media and civic groups thoroughly reviewed safety incidents, which caused

strong public dissatisfaction on the labor training and protection. In addition, the falsification of cement reports and the movement of seawalls in the artificial island roused public doubts on the quality of HZMB. Hence, decision-makers can collaborate with the public by making a public-participated evaluation team that transparently examines the project pros and cons (Xie et al., 2014).

The environmental issue (#3) has an extremely low sentiment score in Zone Two. However, no full public attention focused on the ecological problem in the handover phase. The relevant concerns were mainly from green groups and local residents regarding the air and marine pollution in the project neighborhoods. Therefore, the consultation strategy is eligible for decision-makers to negotiate with the targeted public group directly, thereby preventing the escalation of public concerns (Webler and Tuler, 2006).

Customs clearance (#4) and the local industry development (#7) occupy the highest popularity rank in Zone Three, indicating the public expectations on the significant improvement of these two issues with the completion of HZMB. The two issues are interdependent of each other. For instance, local logistic companies expect the 24-hour custom clearance service to enhance their productivity. In addition, the local tourism association hopes to shorten the waiting time for travelers to pass the customs checkpoints. To improve the quality of customs service and thereby boost the local industry, the involvement strategy is essential for administrators to understand the updated public needs through continuous interactive discussions with the public.

Located in Zone Four, governmental cooperation (#2) and commercial development (#15) have become the least critical public concerns in the handover phase. As the HZMB came close to completion, most coordination works between the three regional governments and the construction of commercial facilities were finalized, which downgraded the concentration of public attention. Therefore, the information strategy is adequate to deal with public concerns on these two issues.

MANAGERIAL IMPLICATIONS

Based on the case study results, the dynamic management strategies of sixteen public concerns identified in HZMB were provided in each project phase, as Table 1 shows. The managerial implications provide a fast guideline for decision-makers from administrative departments responding to each public concern in future megaprojects. According to the discussion from Section Dynamic management strategies for public concerns, the detailed managerial suggestions are as follows.

In the planning phase, the citizen advisory committee is suggested to be established dealing with the public concerns on governmental cooperation (#2) and local connectivity (#9) under the collaboration strategy. The focal group meeting is recommended to implement the public consultation on financial arrangements (#11), alignment options (#0), and local traffic conditions (#6, 8). The public concerns on environmental protection (#3) and commercial development (#15) call for the involvement strategy with public workshops and forums. In the construction phase, the financial issue (#11) is the top public concern requiring joint decision-making by collaboration between decision-makers and public representatives. The focus group meetings with targeted public groups are encouraged to hold across a variety of economic (#7,10,14), operational (#5,8), technical issues (#0,12,13) of the project. Besides, frequent interactive communication is essential to enhance public involvement in conveying their opinions on governmental cooperation (#2) in this phase. Furthermore, the information strategy helps establish a positive project image for the local community (#1) through public exhibitions and open-site visits. In the handover phase, a public advisory committee is suggested to form in the decision-making of operational arrangement (#5,8). A public-participated evaluation team is recommended to organize for responding to public concerns on the review of project pros and cons (#12,13). The public consultation of environmental issues (#3) is encouraged to be directly organized between decision-makers and green groups. The involvement strategy like continuous interactive discussions can help administrators

526 understand public needs on customs service (#4) and local industry development (#7).

527 **<Table 1 Dynamic management strategies of public concerns for decision-makers>**

528 **CONCLUSIONS**

529 This study provides an integrated topic and sentiment modeling approach to achieve dynamic analysis
530 of public concerns in megaprojects by mining knowledge of project-related text documents. There are three
531 models in the proposed automated method. First, a dynamic TOT model explores the critical public concerns
532 from the relevant text and traces the popularity trend of each concern in the project duration. Second, the
533 BERT-based sentiment model is developed to track the public sentiment trend toward each identified concern
534 in the timeline. Third, a "Mirror N" strategic model is proposed in consideration of both public popularity and
535 sentiment. With this approach, the criticalness of public concerns is assessed and the corresponding public
536 participation strategy is provided, including collaboration, consultation, involvement, and information. The
537 approach realizes comprehensive dynamic analysis of public concerns from identification to measurement and
538 management.

539 With the case of HZMB, the proposed integrated modeling approach successfully detects the critical
540 public concerns, reveals the trend of public popularity and sentiment towards the concerns, and summarizes
541 the managerial implications. A total of 16 public concerns are explored from 1748 unstructured project
542 documents. Among them, five public concerns received wide public attention in the project duration. Issues
543 on government cooperation occupied the highest popularity in the decision-making period, while those of
544 environmental protection, local link roads, financial arrangements, and business advancement planning
545 became popular issues among the public twice in the planning and construction phases, respectively. Moreover,
546 the volatile public sentiment was traced in the timeline. In the planning phase, the sentiment value on financial
547 arrangements fluctuated with the discussions of financial proposals. The government cooperation and

548 commercial development issues experienced the significant decrease of sentiment value in the early and
549 middle construction phases. Public sentiment on environmental issues plunged from the late construction
550 phase to the handover phase. Finally, the "Mirror N" strategic model is used to provide the managerial guide
551 for each identified public concern in the various phases of HZMB.

552 There are two contributions presented in the study. Methodologically, an integrated topic and sentiment
553 modeling approach is developed for analyzing dynamic patterns of public concerns in megaprojects, with
554 mining knowledge from a huge dataset of unstructured text documents regarding the project. The proposed
555 method integrates the two mainstream text-mining techniques, topic models and sentiment analysis, to solve
556 the lack of efficient analytical tools for public concerns in the changeable environment of megaprojects.
557 Theoretically, a "Mirror N" strategic model is designed to manage public concerns based on the chronological
558 features of popularity and sentiment from the public, together with four classical public participation
559 strategies. The strategic model provides a precise data-driven managerial guide for decision-makers by
560 bridging the knowledge domains of public participation studies and text-mining techniques.

561 The proposed method can be applied to projects in different regions if text documents are available to
562 provide reliable timestamped corpus regarding public concerns. Apart from public concerns, the method can
563 be extended to detect the dynamics of any other issues that have timestamped text documents, which brings
564 the data-driven managerial approach into the domain of construction project management.

565 **DATA AVAILABILITY STATEMENT**

566 Several or all data, models, or codes that support the findings of this study are available from the
567 corresponding author upon reasonable request.

568 **ACKNOWLEDGEMENTS**

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SUPPLEMENTAL MATERIALS

Supplemental document S1 is available online in the ASCE Library (www.ascelibrary.org).

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Table 1 Dynamic management strategies of public concerns for decision-makers

Phase	*Planning*	*Construction*	*Handover*
Strategy			
Collaboration	2,9	11	5,8,12,13
Consultation	0,6,8,11	0,5,7,8,10,12,13,14	0,3,6,10,11,14
Involvement	3,15	2,3,9,15	1,4,7,9
Information	1,4,5,7,10,12,13,14	1,4,6	2,15

Note:

#0 alignment; #1 local community; #2 cooperation across governments; #3 environment; #4 immigration and custom service; #5 operation on cross-boundary traffic; #6 local traffic in connective areas; #7 local industry; #8 operation on local traffic; #9 local connectivity; #10 urban development; #11 finance; #12 construction; #13 design; #14 regional economy; #15 commercial development

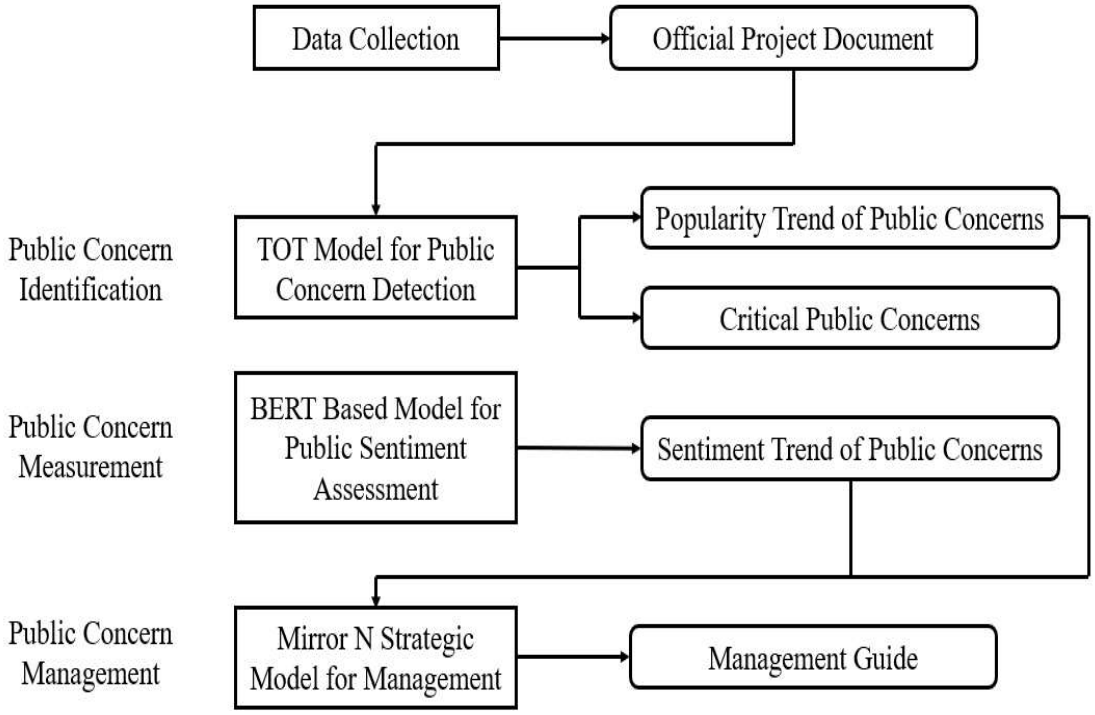

Figure 1. Research framework of dynamic analysis on public concerns

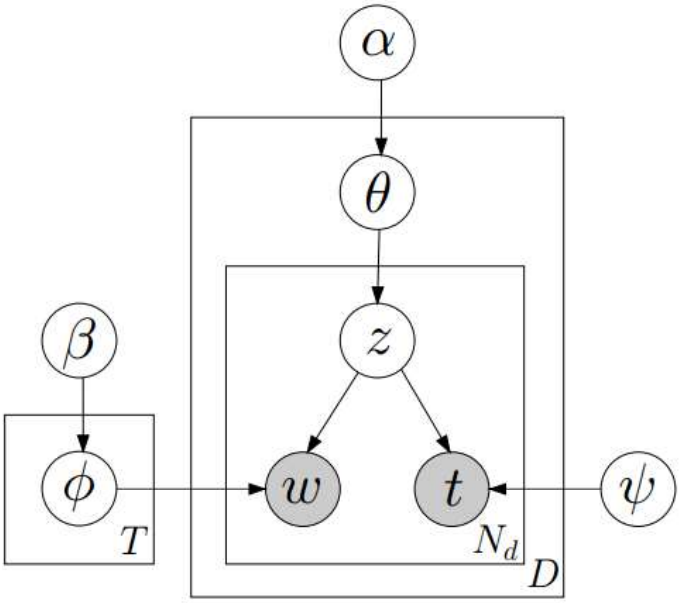

Figure 2. Graphical model of TOT

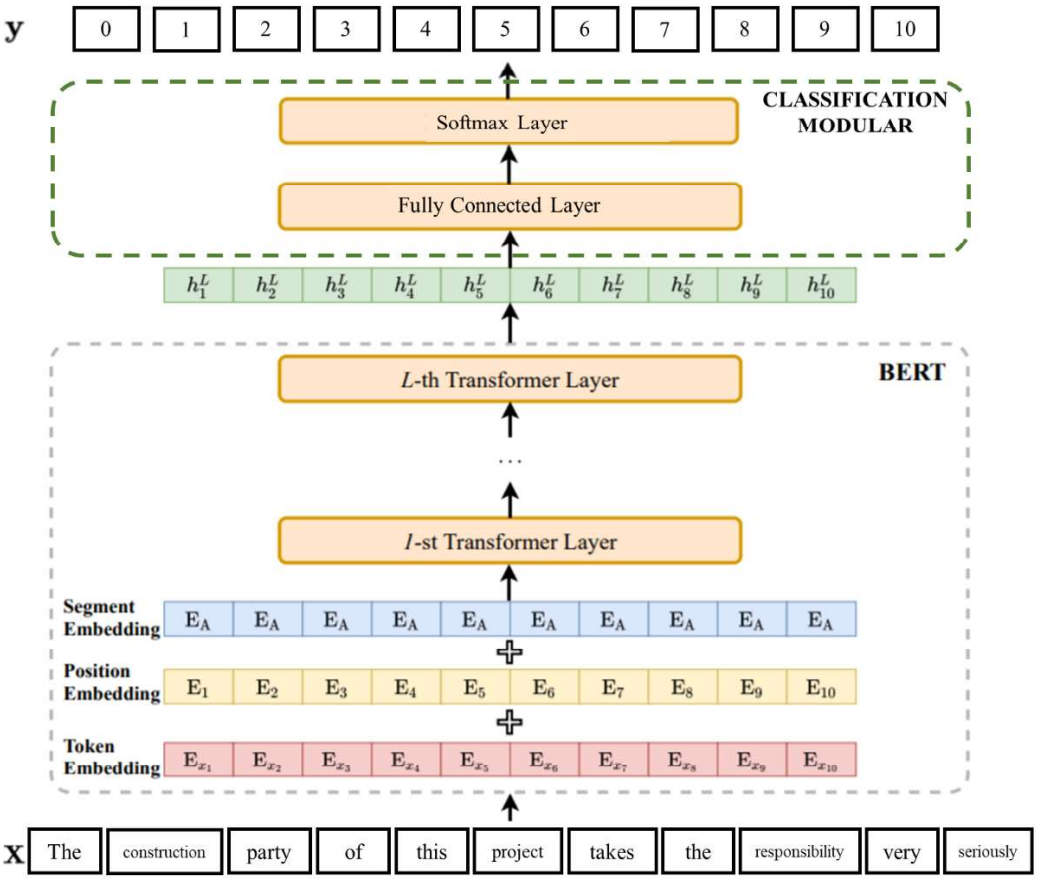

Figure 3. The BERT based sentiment model

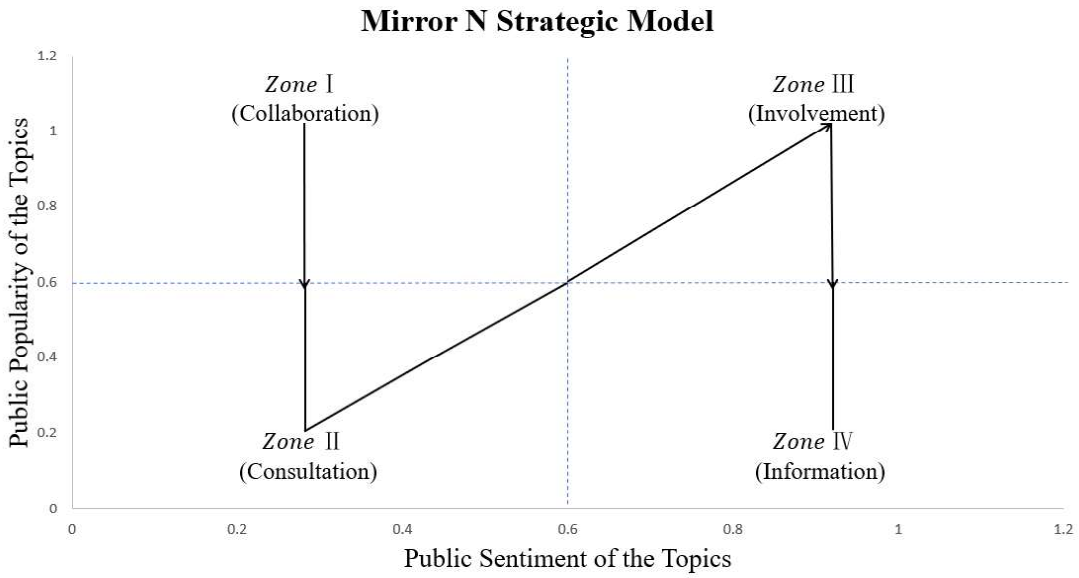

Figure 4. Mirror N Strategic Model for managing public concerns

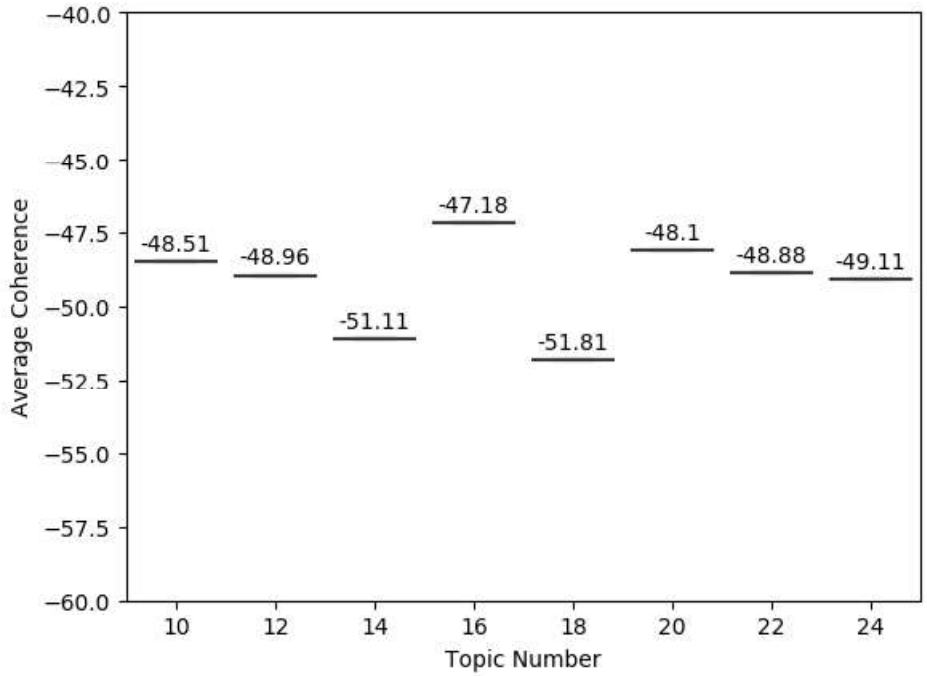

Figure 5. Results of TOT modeling validity test

Figure 6

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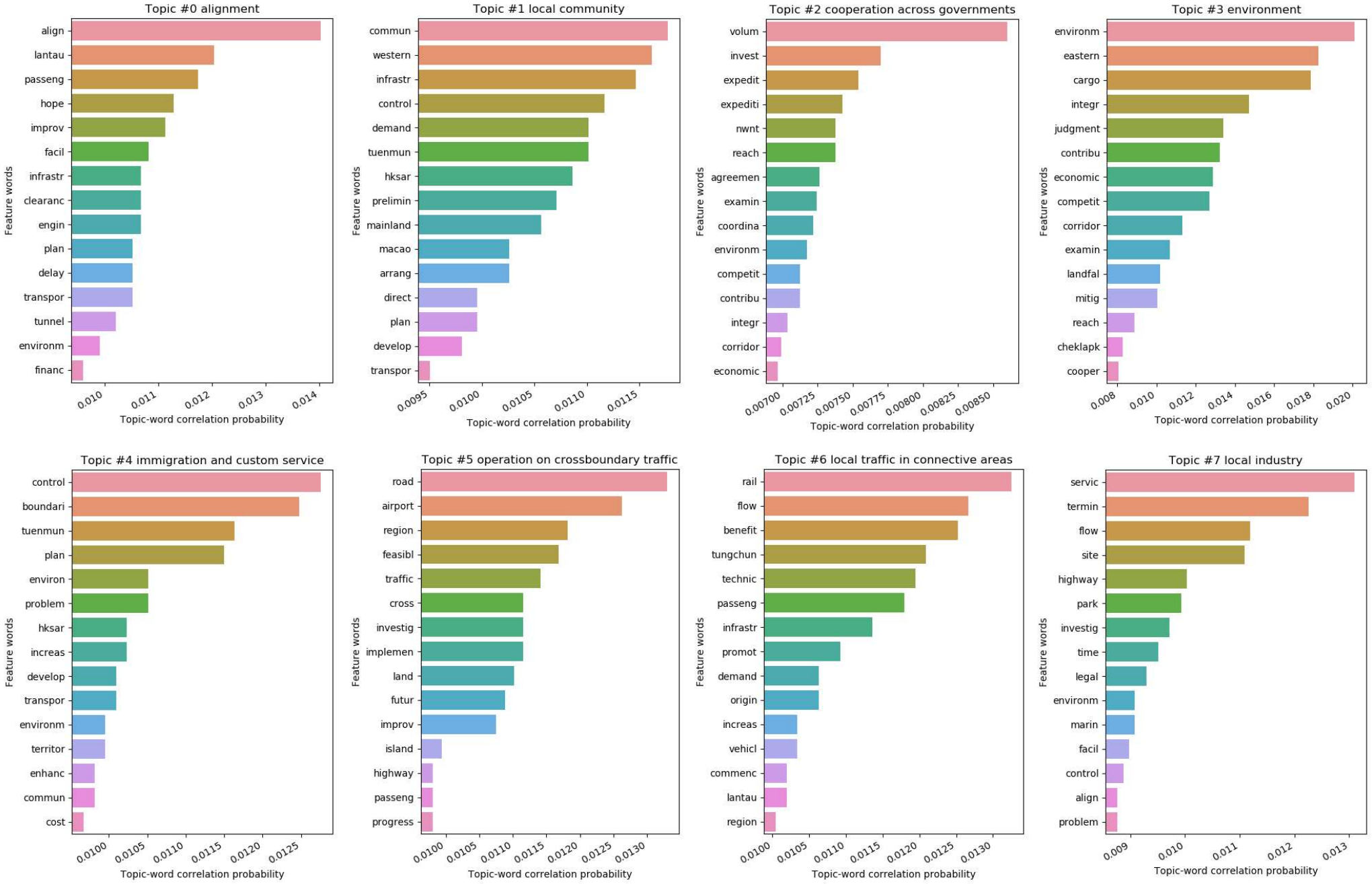

Figure 6. The concept of each topic (# 0-7) with top 15 correlated feature words

Figure 7

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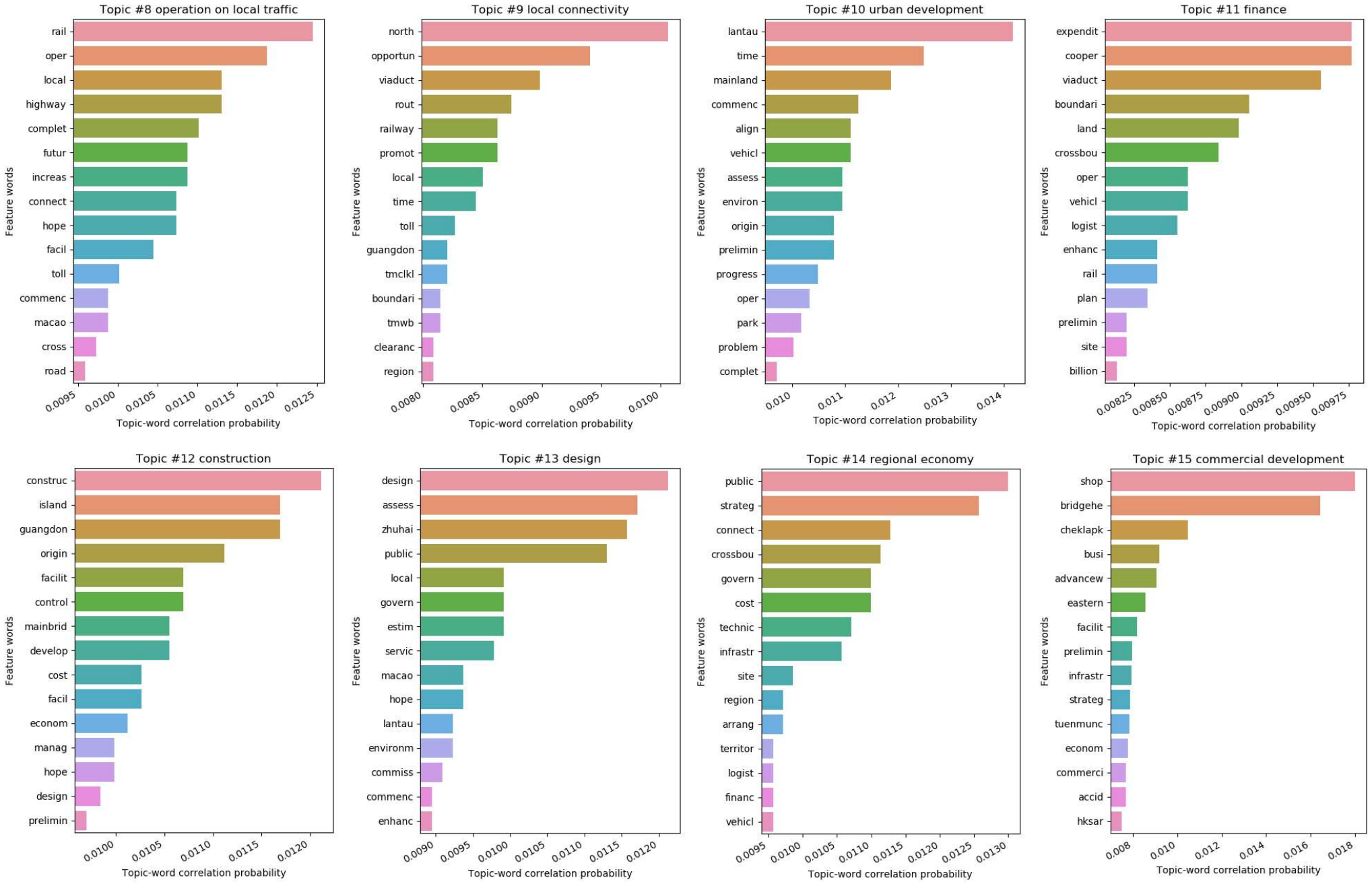

Figure 7. The concept of each topic (# 8-15) with top 15 correlated feature words

Figure 8

Click here to access/download;Figure;Figure 8.docx

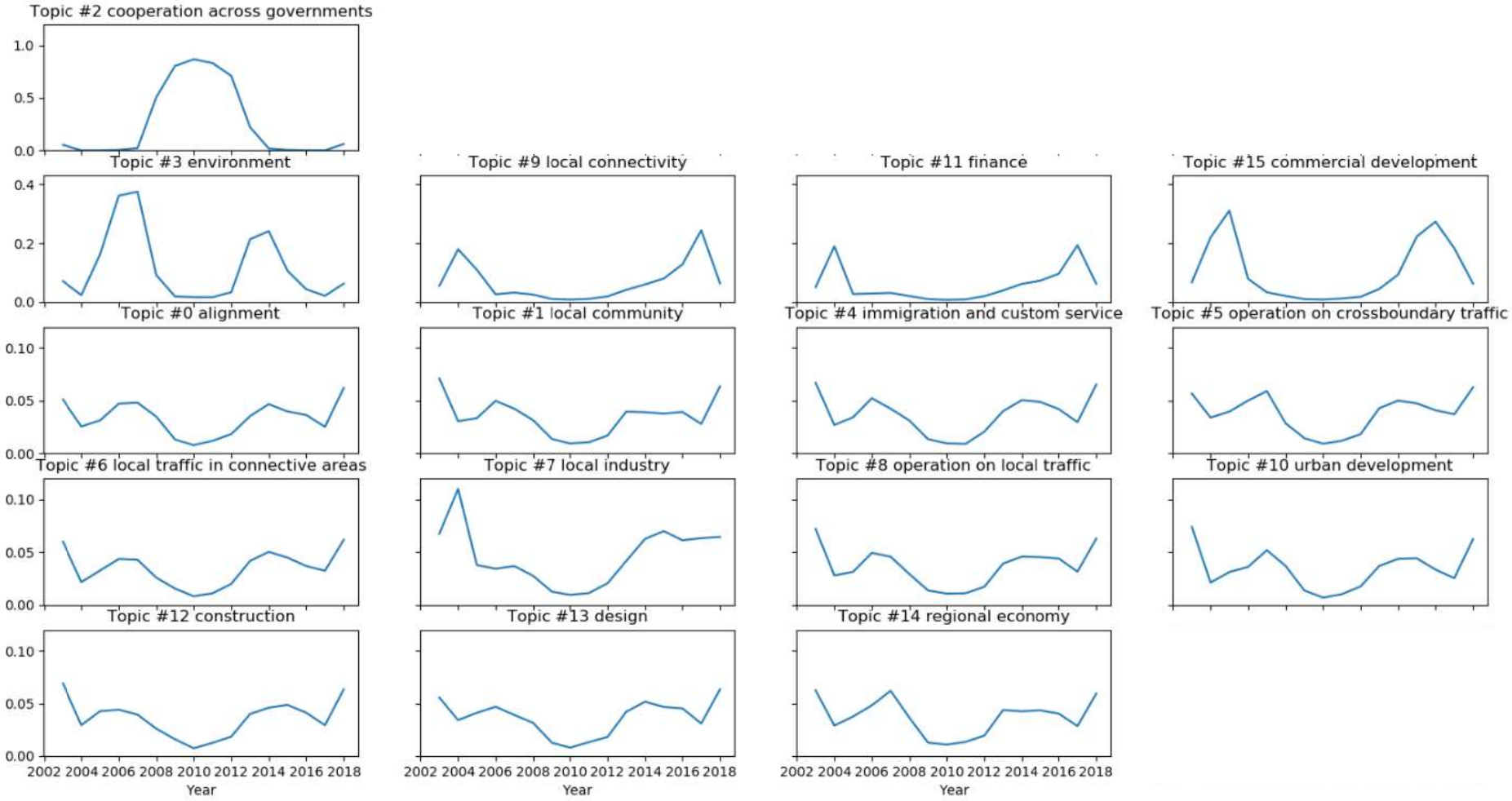

Figure 8. Popularity Trend of Public Concerns in HZMB

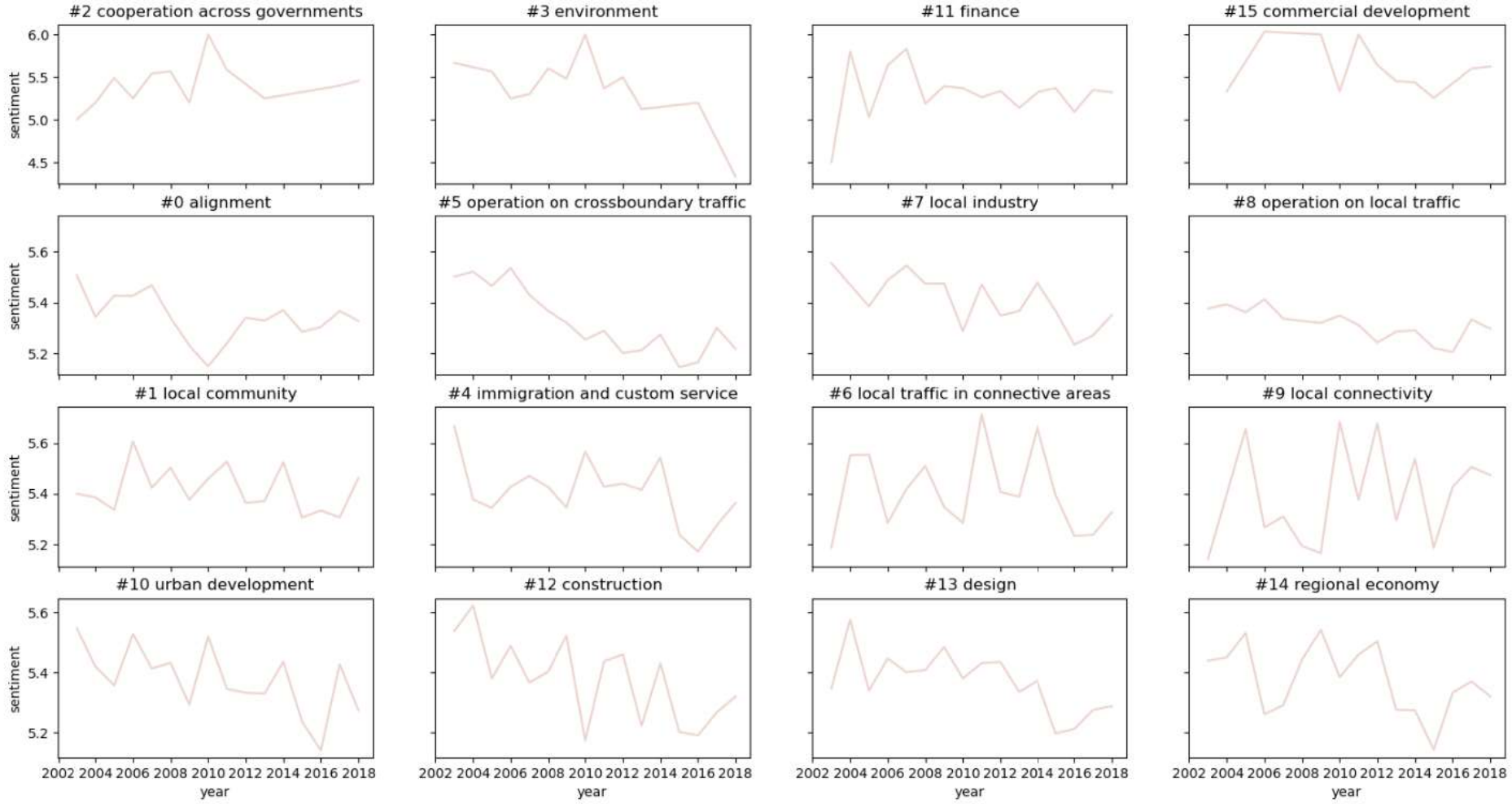

Figure 9. Sentiment Trend of Public Concerns in HZMB

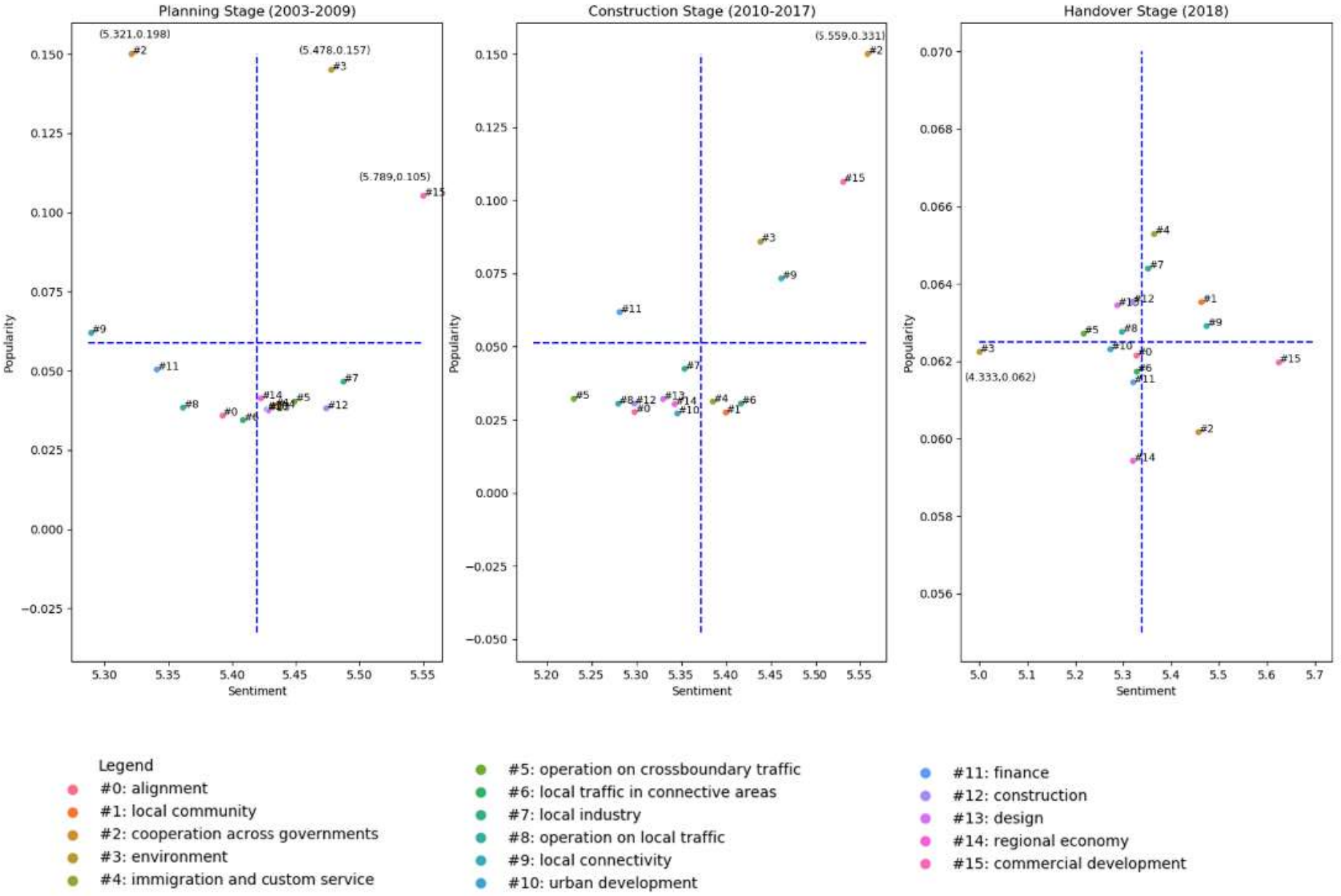

Figure 10. Strategic Map of Public Concerns in HZMB