



METHOD ARTICLE

Smart city perspectives in post-pandemic governance: Externalities reduction policy [version 1; peer review: 2 approved]

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Abstract

Background: The ongoing COVID-19 quarantine restrictions have caused multiple sharp decreases in activities associated with the movement of large masses of people. The economies of regions and cities that are critically dependent on tourist flows related to various segments have suffered. This research aims to provide an economic-mathematical model of smart cities externalities' impact from the point of view of achieving social and environmental goals

Methods: The objective of this study was to develop an algorithm for supporting decision-makers. Methods of mathematical modeling, statistical processing of data received in real-time, as well as methods for finding solutions by expansion into dynamic series are used, and the theory of mathematical games is applied. The theoretical mathematical model presented considers the statistical processing of data provided in real time referring to the performance indicators of megacities.

Results: The activities of administrations and governments aimed at maintaining stability over the past two years have been aimed at reducing the negative impact of the pandemic. The prospect of returning to normal conditions is complicated by a number of factors. The proposed approach allows the development of the fundamental basis for making administrative decisions within individual

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megapolises and in environmental policy on a territory of any scale. The developed mathematical model is abstract by definition and is applied by taking into account specific tasks and criteria. Since the tasks of the administration differ depending on the region and country, the choice of criteria is set individually.

Conclusions: During the period of isolation, the volume of services in the Hotel - Restaurant- Catering/Café (HORECA) segment has decreased, and personnel has also been lost. The reduced pressure on public infrastructure and the departure of migrants means that, in the long term, this work cannot be restored within a short period of time.

Keywords

Digital Interactions, Smart Cities, Sustainable Development, Digital Platforms



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Introduction

Since the late 1990s, thanks to innovations in several decisions and globalization, running a business and the public's way of life have changed significantly.¹ New opportunities for fulfilling one's potential become available to active people. The development of telecommunications systems allows you to organize virtual development teams, while distance learning also reduces the need to be in specific places. The mobility of the labor force became possible due to the elimination of border and customs barriers, and the transport infrastructure was additionally developed, especially in Europe. Therefore, people, especially the younger generation, have become less attached to a settled way of life and choose dynamic movement between locations. At the same time, alpha cities and megacities, which provide maximum opportunities for self-realization, become centers of attraction. The movement of mobility of the labor force within Europe and between other states has led to an increase in the dynamics of the structure of employment of the population. International transport services of all kinds have become available over the world (the proposed mathematical model is equally acceptable for any regions of the world.).

The authors consider the coronavirus crisis as a test of whether smart city technology may mitigate the negative impacts. The COVID-19 pandemic was a black swan event that disrupted the established chains of interaction and completely reshaped the economic landscape of most regions and cities of the world, which are centers of attraction for human flows.² The researchers could define the cities with a preparedness resiliency plan as 'smarter' using the Internet-of-Things (IoT) sensors, cameras etc.¹ Digital transformation allows many businesses to develop seamless working-from-home experiences. The degree of equipment with technical means for analyzing current information about the state of urban infrastructure, its processing for different cities and regions is different. This often depends on the budget of the administration and on legislative restrictions. The most advanced control systems today are in Southeast Asia, such as China, but during the COVID-19 pandemic, telecommunications and data processing systems have been rapidly developing throughout Europe. The importance of IoT systems and machine-to-machine interaction has also increased manifold. First of all, this is the automatic collection of data on the migration of people, traffic on the roads, the expenditure of all types of resources, and the general situation in cities. In addition, BigData technologies based on predictive algorithms make it possible to make decisions with an effect extended over time. The anti-pandemic measures have accelerated broadband consumption growth by over 60%.³

The problem of post-pandemic governance could be described from the point of view of organizing business interaction within the consumer value chain. The idea of forming a consumer value chain was initially proposed by M. Porter in 1985.⁴ This considers the term 'echelon' which relates to the theoretical approaches of modeling multi-echelon supply chain design⁵ and social sustainability assessment of upstream (a set of connected firms that involve raw material extraction and transformation), midstream (production and assembly), and downstream (sales and services) echelons of supply chains.⁶⁻⁹ Some researchers explore solid waste management systems from the logistics and supply chains theory¹⁰ and multi-echelon supply chains under stochastic and fuzzy environments.¹¹

The upcoming removal of restrictive quarantine measures will have a shocking impact on all services and will require the administrations of regions and cities to make informed and calculated decisions.¹² The lack of theoretical propositions regarding sustainable development goals supporting the quality of life in the post-pandemic period refers to the research gap. The authors are attempting to investigate environmental and social goals from the point of view of administrative measures to conquer the negative consequences of coronavirus disease, considering an ecological policy. The authors propose exploring digital transformation in smart cities as a tool for sustainable development, making the logical bridge between the theoretical framework of sustainability concept and common property resources as an environmental asset in a digital era.

This article aims to provide an economic-mathematical model of smart cities externalities' impact from the point of view of achieving social and environmental goals. The result is a set of formalisms^{13,14} that allow the application of scientific methods to find optimal solutions.^{15,16} The proposed approach allows the development of the fundamental basis for making administrative decisions within individual megapolises and in environmental policy fora territory of any scale.

Methods

Study design

The authors propose the extension of the theoretical construction of the process of interaction between the business echelons within value chains.¹⁷ The considered algorithm has been validated in the works.^{17,18}

The researchers consider the definition of the business echelons as various stages of the consumer value chain regarding the complete promotion cycle of any product taking into account the features of digital ecosystems.¹⁹ The digital transformation of both logistics networks and marketing channels is a tool for implementing the smart city perspectives in

post-pandemic governance.²⁰ The basis for this study was the theoretical research on the workload of megapolises. We suggest considering Alpha cities as centers of the following group of activities:

- business events, meetings, incentives, conferences, and exhibitions corporate segment;
- the flow of people attending landmark social and sporting events, and social life phenomena;
- sightseeing, places of interest (POI) of cities of the level from Alpha to Alpha ++ by the Globalization and World Cities Research network (GaWC)²¹ rating;
- medical services, modern hospital centers;
- social mobility of workers in megapolises;
- student mobility (a characteristic feature of most megapolises).²²

Data collection

The dependency regarding the mentioned factors post-pandemic, could be considered stochastic based on quantitative data, reflecting demand's seasonality with an annual frequency. The authors group this set of indicators according to the following main features: determined by the business environment; restrictions of a natural nature; factors regulated by the authorities; restrictions dictated by cultural, religious and national characteristics. Through mathematical analysis,^{23,24} we decomposed this dependency into a Fourier series to deconstruct its complex form into several harmonic components (each of them being a periodic function). The authors considered the seasonality function of the loading resource. The pronounced seasonality is due to the multiple growth of tourism during summer holidays, vacations of students several times a year, periodic international events such as sports competitions, cultural festivals, public holidays, Christmas holidays, etc. The use of the Fourier method makes it possible to obtain an answer to the main question of the study. In this work, it is the analytical solution that serves as the basis for the development of predictive software products. Since a lot of time passes between the adoption of decisions of all levels of government in megacities and their implementation, the possibilities of mathematical modeling allow city administrations to take the necessary measures in advance to prepare for a sharp change in the conditions for the functioning of all city services. The exit from the pandemic has led to a dramatic change in living conditions. It also imposes extraordinary requirements for adaptation for all levels of life organization of any territories and any specifics.

Data analysis

This article obtained an analytical solution in quadratures, scalable to each system. Using the superposition of the obtained solutions with weights corresponding to the initial decomposition, it became possible to get an integrated dependency.²⁵ The proposed approach allowed formalizing the resources of the megapolis in the form of a dynamic task. The researchers achieved results in a group of solutions based on the dependence²⁶ of the environmental costs. In our study, groups of environmental factors are identified, such as restrictions on utilities in terms of waste, sewage, drinking water supply, throughput of highways, taking into account air pollution by road and other transport, the limiting capabilities of medical institutions and the permissible anti-epidemic level of concentration of people. In addition, we additionally take into account restrictions on the supply of the territory with all types of material life support and the limiting capabilities of public order services. The authors recommended the administrative regulation for decision-making, improving the quality of life in megapolis based on the developed theoretical approach considering the digital transformation as a tool for sustainable development. We have proposed a mathematical model, brought to the result of the solution. The specific application of the developed formalisms depends on the tasks and priorities set and may vary for different cities and regions. The authors used the Fourier method aiming to obtain an answer to the main question of the study to test the formalisms presented in the results section. In this work, the researchers are attempting to develop the analytical solution that serves as the basis for the development of predictive software products. The methods used in the study belong to the category of mathematical modeling and big data processing technologies. Authors paid special attention should to the use of decomposition of complex dependencies into harmonic components.

Results

The construction of a mathematical model is necessary to select optimal solutions. The new industry 4.0 technologies (e.g., cyber physics systems, big data, IoT, etc.) allow for extending the field of financial logistics implementation based on the digital transformation of logistics^{18,27} and digital twins.²⁶ We used the technology of developing a digital twin, which allowed us to apply the methods developed in mathematics to find the optimal result. The authors used the concept

of digital twin being developed in previous works regarding digital logistics.^{26,28} This research aims to develop digital twins of the considered process. The authors introduce several notations for the arguments used.²⁹

The dependence of the load on time t is $\Lambda(t)$. Since $\Lambda(t)$ changes unevenly throughout the year, reflecting the load acting on the resources available in the region or the megapolis, we will represent its decomposition as a set $\lambda_i(t)$ (where $i = 1, 2, \dots$). The authors introduce a periodicity T characteristic of the load on resources. T is equal to the annual cycle. The researchers define a set $v_i(t)$ for the values of the probabilities of the use of the common resources of the territory. Next, we introduce $E_k(t)$ functions that define a set of system states together with a set of their probabilities:

$$p_i(t) = \varphi_i(t) + \alpha_i(t).$$

In this expression, $\varphi_i(t)$ is the $T/2\pi i$ periodic, and the term $\alpha_i(t)$ satisfies the condition $\lim_{t \rightarrow \infty} \alpha_i(t) = 0$, and $\forall i$. In this interpretation, $\varphi_i(t)$ reflects the stationary probability $p_i(t)$. Next, we can consider the sequence:

$$p'_{0i}(t) = -\lambda_i(t)p_{0i}(t) + v_i(t)p_{1i}(t), \quad p'_{1i}(t) = -v_i(t)p_{1i}(t) + \lambda_i(t)p_{0i}(t)$$

together with the complete group condition:

$$\sum_i p_i(t) = 1.$$

After carrying out an algebraic transformation of the form:

$$p'_{0i}(t) = -[\lambda_i(t) + v_i(t)]p_{0i}(t) + v_i(t)$$

at zero conditions

$$p_{0i}(0) = \alpha_i \leq 1, \quad p_{1i}(0) = 1 - \alpha_i \leq 1,$$

it becomes possible to obtain the desired system already in quadratures in the form:

$$p_{0i}(t) = e^{-\int_0^t [\lambda_i(x) + v_i(x)] dx} \left[\alpha_i + \int_0^t v_i(x) e^{-\int_0^x [\lambda_i(z) + v_i(z)] dz} dx \right].$$

The authors denote $\varphi_i(t) = \int_0^t [\lambda_i(x) + v_i(x)] dx$, as well as k , which satisfies the inequality: $kT \leq t < (k+1)T$. The researchers suggest an expression for the calculation of $\varphi_i(t)$:

$$\varphi_i(t) = ka_i + \int_0^\tau [\lambda_i(z) + v_i(z)] dz,$$

Here, it is assumed that: $a_i = \int_0^T [\lambda_i(x) + v_i(x)] dx$, $\tau = t - kT$.

Similarly, the authors express: $\int_0^t v_i(x) e^{\varphi_i(x)} dx = \sum_{l=1}^k \int_{(l-1)T}^{lT} v_i(x) e^{\varphi_i(x)} dx + \int_{kT}^t v_i(x) e^{\varphi_i(x)} dx$, and this gives us $p_{0i}(t) = e^{-\varphi_i(t)} \left[\frac{b_i}{e^{\varphi_i} - 1} + \int_0^\tau v_i(x) e^{\varphi_i(x)} dx \right] + e^{-ka_i - \varphi_i(\tau)} \left[\alpha_i - \frac{b_i}{e^{\varphi_i} - 1} \right]$,

In this case, the designation for the parameter is introduced: $b_i = \int_0^T v_i(x) e^{\varphi_i(x)} dx$.

The authors search for the optimal solution on the obtained basis³⁰ using the common approach of digital twin concept.^{13,31,32} To do this, we formulate the problem in a general form. The authors then define the number of users of the resources as n . In this case, the load l_i , where $i = 1 \dots n$, reflects the of each user's externalities for the vector: $\bar{L} = (l_1, l_2, \dots, l_n)$.

The total load $L^* = \sum_{i=1}^n l_i$.

The researchers introduce the weighted average^{14,30,33–35} variable costs U_i and the dependence $g_i(l_i)$ of the revenue of each user. Due to the limited capacity of the shared resource, starting from $\bar{L} > \bar{L}_R$, the profitability drops. This corresponds to the fulfillment of the condition $g'_i(l_i) < 0$. Moreover, due to the negative impact of the externalities of the specified n users, the second derivative is subject to the condition $g''_i(l_i) < 0$.

Then, the profit of the i -th user is $R_i = l_i g(l_1 + l_2 + \dots + l_n) - U_i l_i = l_i g_i(L) - U_i l_i$. Based on the Nash equilibrium principle,³⁶ there is a value l_i^* for $i = 1 \dots n$, at which R_i reaches a maximum for any components \bar{L} : $\bar{L}_i^*(l_1^*, l_2^*, \dots, l_{i-1}^*, l_{i+1}^*, \dots, l_n^*)$. We find the extremum points from the conditions (for the calculation): $\frac{\partial R_i}{\partial l_i} = 0$, at $i = 1 \dots n$. Denoting the sum $l_{-i}^* = \sum_{k \neq i} l_k^*$, the authors obtain $g(l_i + l_{-i}^*) + l_i g'(l_i + l_{-i}^*) - U = 0$ for $i = 1 \dots n$, which gives

the desired value of $L^* = n \frac{U - g(L^*)}{g'(L^*)}$. Consequently, the extremum is reached at $L_0 = \frac{U - g(L_0)}{g'(L_0)}$. Since the condition $n > 1$ is satisfied, it follows that $L^* > L_0$. This proves the obtained result.

The mathematical model formulated in the article provides an opportunity for developing several software applications (however the authors are attempting to develop the common theoretical approach). Since the calculations are scalable, it is possible to cover most of the critical areas of economic activity that affect the quality of life, the environment, and the economic performance of a given territory. First of all, the authors were guided by publicly available specifications V182 (<https://www.bsigroup.com/en-GB/smart-cities/Smart-Cities-Standards-and-Publication/PAS-182-smart-cities-data-concept-model/> accessed on 27 April, 2022). In this case, we consider the result as an algorithm acceptable for embedding in the smart city digital platform. The proposed approach allows the development of the fundamental basis for making administrative decisions within individual megapolises and in environmental policy for the territory of any scale. The developed mathematical model is abstract by definition and is applied taking into account specific tasks and criteria. The theoretical recommendations are expected to be implemented for designing a customer value chain and digital logistics network in smart cities and smart territories. The governing measures consider planning optimal organization of suppliers in a digital logistics network, taking into account the interests of stakeholders and the priorities of the sustainability concept. The developed method will add value to the field of planning smart cities and smart territories based on the model including the economic interests of customers, profit indicators, the delivery time of goods, and reliability of supplies. The usage of this method allows customer value creation by developing a customer-oriented approach and achieving public consensus on an integrated network structure. The expected value of peer review could provide the best available path for designing smart cities' logistics networks to gain social, environmental, and governing goals of the sustainable development concept.

Discussion

The authors suggest discussing the wide area of issues regarding the smart city concept based on digital interaction within a constantly evolving sustainable environment. Due to the publicly available specifications, the decision model has grown significantly. Big data technologies, high-speed mobile means of information transmission, and urban management algorithms have become the norm. However, predictive methods are required for black swan events such as the COVID-19 pandemic.^{37–39} The evolution of smart cities could be considered in the context of the discussion of the developed algorithm compared to existing research. The authors are attempting to investigate the complex task of the sustainable development in post-pandemic situation. The existing approaches consider the COVID-19 pandemic as a continuous crisis having a negative impact on the sustainable development, but do not take into account the difficulties caused by post-pandemic crisis. The researchers aimed to develop an approach considering the digital transformation as a tool for achieving Environmental, Social, Governmental (ESG) goals with supporting measures as a common resource access policy.

The authors believe that decision-makers need predictive methods for the post-COVID-19 transition period. Undoubtedly, removing restrictions will entail serious negative consequences for the economy, ecology, and municipal infrastructure of megapolises. It is necessary to calculate the optimal mode of interaction between the administration, government, and experts in commerce and the service sector that determines the lives of the population and arriving people. The developed model solves the most challenging task of organizing an increase in the volume of services concentrated in a limited location while minimizing negative externalities. The framework of the developed approach is limited by mathematical assumptions and methods of game theory. The authors propose a topic for future research related to digital transformation as a tool for achieving sustainable development goals.

Exploring methods and models of digital logistics relying on different conditions of smart cities' sustainable development could be a topic for future research in a couple with several points of view in works.^{13,40–42}

Conclusions

The authors considered a systematic approach comprising the sustainable development concept and smart cities' evolution based on digital technologies. This article obtained an analytical solution in quadratures, using the superposition of the obtained solutions with weights corresponding to the initial decomposition. The proposed approach allowed formalizing the resources of the megapolis in the form of a dynamic task. The researchers achieved results in a group of solutions based on the dependence of the environmental costs. The authors recommend the administrative regulation for decision-making, improving the quality of life in megapolis considering the digital transformation as a tool for achieving ESG goals.

Currently, the administrative regulation measures for supporting sustainable development in megapolises use heuristic methods in their current activities. The severe disruption caused by the pandemic has shown the unsustainability of the current management practices. No dynamic analysis and search for optimal solutions are carried out in the decision-making process. Such difficulties are primarily due to the complexity of considering many factors and the lack of scientifically based theoretical models that consider economic indicators. However, the upcoming release from the restrictive measures of the quarantine regime can lead to much greater shocks. The developed methodology makes it possible to calculate the balanced benefit for all participants in the activity, taking into account externalities and choosing alternative options.

Data availability

No data are associated with this article.

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Elena Schislyaeva

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The authors of the article rightly believe that mathematical models designed to predict the dynamics of investment projects with risky returns are necessary, first of all, for socially responsible activities. Long-term planning distinguishes the work of institutional investors such as pension funds. These financial players differ from other market participants by their incomparably longer business cycle. Accordingly, the social significance of their activities and the impact on the quality of life of all segments of the population increase. The need to develop a methodology for assessing sustainability is also dictated by the increased role of digital technologies, as well as the ability to receive the most relevant information for analysis online. In addition, as socially oriented subjects, in addition to the tasks of making a profit, the most important priority is the sustainability of the development of society and maintaining the quality of life. Such institutional investors in the world have a significant impact on the business climate due to the scale of their activities. In this work, the problem of sustainability of investment activity is investigated. The reviewed work outlines the methods and results of a study aimed at the digital transformation of methods for forecasting long-term institutional investments.

Is the rationale for developing the new method (or application) clearly explained?

Yes

Is the description of the method technically sound?

Yes

Are sufficient details provided to allow replication of the method development and its use by others?

Yes

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital logistics and Smart supply chains

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 06 October 2022

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Bilal Khalid 

KMITL Business School, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

Abstract

- The overview of the abstract was well presented, but there is still room for improvement.
- **Methods:** The methods should be improved to capture the type of study, procedure, population, and method of data analysis.
- The abstract will also benefit from the inclusion of study limitations and recommendations if any.
- The authors can also add one more keyword to capture the essence of the study.

Introduction

- The importance of the research was stated, and I commend the authors on the novel approach to presenting the study.
- The introduction makes all the arguments for the benefit of smart cities and the possible impacts of the COVID-19 pandemic. The authors have cited adequate literature to support their arguments.
- The authors were able to present the motivations for the study and highlight the importance of smart city projects in mitigating pandemics.

Methods

- The introductory part of the Methods section is scanty. The authors should discuss the relevant theories, models, and processes adequately to show an understanding of the topic of research.
- The research method adopted for the study seems adequate.
- The procedures, sampling techniques, and instruments have been adequately described. The researchers have clearly outlined these showing a clear understanding of the

procedures, data collection, sampling technique and instruments, and method of data analysis adopted for the study. Authors should justify the use of the Fourier method in the methodology.

Results

- The appropriate analysis was used to present the results from the data collection process.
- The results were clearly presented and explained. The equations all follow a logical order making it an interesting read. This is the part I enjoyed the most so far in my review of this paper.
- The results section does not need further improvement. The results are clearly and lucidly presented.

Discussion

- The authors can improve the discussion by presenting their impacts using the equations in sequence. Show the implication of the findings based on the presented mathematical equation.
- The discussion can be improved by adding theoretical and managerial implications.
- I suggest adding at least one more paragraph to the discussion. It is too short in its current form.

Conclusion

- The conclusion section addresses all the points by summarizing the outcome. The authors can improve the conclusion by including the study recommendations and limitations.

Title

- The title is appropriate and expansive enough to support the ideas that the manuscript represents.
- The title is fine as it is.
- The title needs no further improvement.

My summary of the paper is that the topic is topical, and readers would be interested in the topic. The contributions of the paper are clear even though the discussion section does require minor improvements. The discussion should be based on the research results and how they interact with the literature for one to be able to understand the contribution of this manuscript. The findings are novel to a lesser extent. This may improve when the authors situate their discussion in the findings of the mathematical equations. The paper is not plagiarized. The paper is suitable for an international audience as it can be applied in any region. There were no country-specific concepts explained. There are minor corrections needed in the manuscript, especially in the abstract, methodology, and discussion. My overall recommendation would be to accept the article with minor corrections.

Is the rationale for developing the new method (or application) clearly explained?

Yes

Is the description of the method technically sound?

Yes

Are sufficient details provided to allow replication of the method development and its use by others?

Yes

If any results are presented, are all the source data underlying the results available to

ensure full reproducibility?

Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Sustainability, Business Management, Industry 4.0, Smart Cities, Technology Adoption, Consumer Behavior.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

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