Intelligent Decision Support During Hospitalization in a Pandemic: Methodology and Process Model

Alexander Smirnov, Nikolay Teslya, Nikolay Shilov
SPC RAS
St.Petersburg, Russia
{smir, teslya, nick}@iias.spb.su

Elena Moll
ECMD, Management Training Center "MMK"
St.Petersburg, Russia
moll@neva.ru

Abstract—**The spread of new diseases in the face of growing urbanization can lead to a high peak load on the healthcare system. Predicting the emergence of a new disease and its potential danger for humans is a difficult task. In this regard, it is important to support the adoption of operational decisions on the hospitalization of patients in any new pandemic. A methodology is proposed that combines support for decision-making on hospitalization, based on solving an optimization problem for distributing the load on hospitals, analyzing heterogeneous data to form an array of constraints when solving an optimization problem, and exchanging electronic medical records between the main actors to provide complete information about the patient. The paper analyzes the decision support process during hospitalization to determine the main parameters that should be taken into account in the context of the optimization problem when making a decision on hospitalization.**

I. Introduction

Nowadays, due to the high degree of urbanization and mobility as well as environmental changes, the world is faced with the problem related to the rapid (explosive) spread of new dangerous diseases, which cause significant damage to the stable development of individual countries and the world economy. Measures taken in the context of epidemics and pandemics should be aimed not only at slowing their spread but also at minimizing the consequences, which, as the current situation with the COVID-19 coronavirus shows, can be very significant for the population and states [1].

Any epidemic requires the healthcare sector to organize as efficiently as possible and consolidate resources to fight it. In the case of diseases with a long history, such as influenza, tuberculosis, MERS, SARS, solutions have already been developed and tested to reduce the negative effect in terms of both mortality and the general impact on the economy and state functioning. However, the current coronavirus epidemic has shown that when a previously unknown disease appears, the available standard solutions may not be enough, and in many cases, prompt adoption of new decisions is required, based not only on existing experience but also on the analysis of the current situation.

Inconsistency in the operation of various services focused on resolving the situation, as well as unpredictable behavior of people can sometimes lead to negative consequences. In particular, the aggression and optimization of the health care system can ultimately lead to a shortage of doctors, equipment, and medicines, and, consequently, to an increase in the number of deaths caused by the disease [2–5]. With a decrease in the efficiency of the health care system, there may be problems such as a shortage of medicines, an increase in the waiting time for an ambulance, both when sending an ambulance to a patient, and when transporting a patient to a hospital. At the same time, in a pandemic, the available resource for the treatment of other diseases decrease, which can negatively affect the mortality statistics. The introduction of severe restrictive measures in the absence of justification and mistrust can lead to a significant increase in the level of stress and discontent, which ultimately can develop into a denial of recommendations and protests [6–8]. All this is an additional motivation for the development of a decision-making system for hospitalization in a pandemic, allowing to distribute the burden on the healthcare system.

Thus, when deciding on measures to combat the source of the pandemic, it is necessary to consider multiple direct and indirect parameters of society. Among the direct objective parameters, one can select the number and distribution of hospitals, the number of ambulances, the number and structure of medical personnel, and the supply of medicines. Indirect parameters include the level of decision approval by the society, the level of stress of both society and individuals.

The paper proposes considering a narrower problem associated with the hospitalization of patients during a pandemic. A methodology for using information technologies to support decision-making during hospitalization is proposed. It is based on the division of the problem into two tasks: 1) making a decision on hospitalization with the selection of an ambulance and 2) the selection of a hospital to which the patient must be delivered. For each task, several parameters are estimated that describe both the quantitative characteristics of the task, such as the availability of vacant places (beds), the average hospitalization time, the number of ambulances, the cost of treatment, and the qualitative parameters associated with the psychoemotional load on patients, dispatchers, and doctors.

In a pandemic, it is also important to exchange information quickly through a trusted environment. For this purpose, it is proposed to use the distributed ledger technology. It proposes to record the number of calls, the number and results of tests performed, information about hospitalization, and the current state of the hospital (vacant beds, personnel, equipment, and medicines).

Within the framework of the developed methodology, it is assumed that access to the distributed ledger is being carried out through contracts, which implement the logic of decision-making based on the data available in the ledger. Thus, the entire process from the moment when a patient comes to the hospital till to she/he is discharged from the hospital can be recorded and analyzed to improve the quality of decisions in the future.

The paper is structured as follows. Section 2 describes the current state of research on the use of information technology to support decision-making in healthcare. Section 3 describes the decision-making methodology for hospitalization in a pandemic. Section 4 contains a description of the hospitalization process and the parameters that should be taken into account when making an appropriate decision. In the conclusion of the work, a general conclusion and directions for further work are given.

II. RELATED WORK

The use of information technologies in healthcare is currently an active and promising area of research. The range of their applications is very wide: from storing medical records, in which all parameters of a patient and her/his health history are saved [9], to the use of artificial intelligence for identifying diagnoses and searching for medicines for a specific disease of a particular patient [10,11].

In recent years, major breakthroughs have also been made in the field of telemedicine. Compact wearable devices have been developed, equipped with sensors for measuring basic vital parameters (heart rate, blood pressure, blood oxygen saturation, compact ECG devices, etc.) [12], physical activity parameters (fitness trackers) [13], as well as the healthcare information systems collecting and analyzing data from wearable devices. The development of video communication systems has provided for the possibility of remote examination and consultation of the attending physician. Upon gaining access to the accumulated information, as well as in the presence of a high-quality communication channel with the patient, the doctor can, without harm to his/her health, provide assistance that does not require physical contact and form recommendations for treatment or health maintenance [14]. The use of wearable devices is also expected to be of significant help in the current coronavirus situation [15],[16].

The development of various systems for monitoring the patient's condition, as well as the compilation of unrelated data banks, is a serious obstacle for the further development of digital medicine. In many works, it is noted that the weak connection between different systems significantly complicates the formation of a general picture of the patient's health [9],[17]. The solution to this problem is to ensure interoperability between different systems and automatic data analysis, as well as providing doctors with simple and secure access to the data and analysis results. Interoperability is considered at different levels [17],[18]:

- technological (providing data exchange channels),
- syntactic (synchronization of data exchange formats),
- semantic:
  - terminology synchronization (MEDCIN, a system of standardized medical terminology [19] or ICD-11 from WHO [ICD-11]),
  - values of data parameters,
  - formation of knowledge bases, nomenclatures, and ontologies (for example, more than 850 medical ontologies are presented on the portal http://bioportal.bioontology.org/),
- organizational (formation of protocols for the secure exchange of data and knowledge, creation of a legislative base regulating the exchange).

Availability of wider sets of data enables making more accurate diagnoses by doctors, apply artificial intelligence for data analysis, and conduct larger-scale studies due to a bigger amount of initial data [9],[21].

Since ontologies are a universal mechanism for representing knowledge, methods developed for other areas of knowledge management can also be used to work with medical ontologies. In particular, when forming operational decisions at the time of hospitalization, it is necessary to consider the context of the current situation in order to select the ambulance team, the route, and to define the distribution of patients to clinics. Significant results in the field of context analysis and the creation of information systems that ensure interoperability between various participants have been developed for advancing in such areas as smart city, the Internet of Things, and the Industrial Internet of Things. In particular, research is underway on the formation of models for the integration of cloud infrastructures, social networks, and semantic technologies [22–24]. The possibilities of sensory perception of the environment and its use for monitoring the situation and making context-dependent decisions are investigated [25–28]. In all the studies cited, it is noted that considering the context when forming a recommendation is an important point that affects the quality of the decision.

It should also be noted that the use of information technology in healthcare is focused on the processing of information that is usually classified as personal data and medical secrecy. This requires corresponding levels of security for the subsystems responsible for processing, storing, transferring, and providing access to the information. In the event of an epidemic, however, it is necessary to provide online access to this information [29]. The recent advanced studies suggest an application of the distributed ledger technology based on the blockchain concept to solve this problem, as well as smart contracts technology that expands its capabilities. The research efforts are focused on creating scalable systems for collecting readings from sensors that monitor the patient's condition [14],[30], creating distributed systems for accessing patient data during routine examinations, and making diagnoses in case of illness [30–32].

It is also worth noting existing interdisciplinary research combining the technologies of the Internet of Things, supply chains, and the distributed ledger in healthcare. Thus, in [33], a system is proposed that collects data from patients using unmanned aerial vehicles equipped with special equipment. The collected data is encrypted and moved to the nearest server, where it is decrypted and put onto a medical record, access to which is organized by calling functions of smart contracts implemented using the Solidity language in the Ethereum blockchain platform. This scheme provides remote diagnostics using professional equipment, with full protection of all personal data of the patient from the moment of measurement to presentation to the doctor.

Another study suggests using blockchain to control the vaccine supply chain [34]. Within the framework of the developed system, the control of the stages from the creation of a vaccine to its application by a doctor is provided. This enables tracking the distribution process, covering the population with the vaccine, and is compliant with the conditions and terms of transportation and storage of the vaccine, which makes it possible to avoid negative consequences caused by damage of the vaccine due to any violation at any stage of delivery. Additionally, the system includes a recommendation module based on a neural network of the LSTM (long short-term memory) model for assessing the vaccine demand based on the results of previous vaccinations. The interaction of participants in the supply chain is carried out through smart contracts implemented based on the Ethereum platform.

III. Decision support methodology for Hospitalization during a pandemic

Decision support involves analyzing the regulators of human behavior in the context of epidemics and pandemics. The coordination of decisions is centered around the impact of behavior regulators in COVID-19, which include legal (rigidly fixed, generally binding), organizational and professional (regulations, rules adopted in a certain professional community), organizational and cultural norms (implied, characteristic of individual organizations, for example, hospitals and services), as well as individual norms (moral and psychological). The legal norms are the easiest to formalize in a mathematical model. The analysis of organizational and professional norms requires additional research since some of them are recommendatory and may have different interpretations. For example, the British Medical Association (BMA) has published ethical guidelines concerning the COVID-19 pandemic. All resource allocation decisions must be “reasonable in all circumstances, based on the best available clinical evidence and judgment, based on clear ethical principles and rationales, best agreed upon in advance, given that these decisions may require urgent revision in changing circumstances” [35].

The use of these schemes can be relevant and justified via considering the rather high contagiousness of coronavirus infection, which carries high risks for medical personnel and others [36]. In general, the issue of organizing the supply chain of medicines and products, as well as remote examination in an epidemic became relevant after analyzing the consequences of new coronavirus infection. In particular, the issues of stability of existing supply chains in crisis conditions, assessment of the consequences of failures, and assessment of risks associated with the need to quickly adapt to new conditions are discussed [37–40].

To support decision-making on hospitalization in a pandemic, the following methodology is proposed (Fig. 1). There are 5 types of actors involved in the hospitalization process: the patient, the attending physician, the dispatcher, the ambulance team, and the hospital. Their joint work can be formalized in the form of an optimization problem, the solution of which will be the distribution of patients among hospitals. The task can be broken down into two subtasks: the distribution of ambulances to patients for testing and the distribution of patients with a confirmed diagnosis to hospitals. The constraints in these tasks will determine the current state of hospitals, ambulances, and the economic and social impact of hospitalization. To assess the economic and social effect, it is proposed to evaluate people's behavior using a mathematical model that takes into account the mutual influence of decisions made on a person's condition and his reaction in case of an

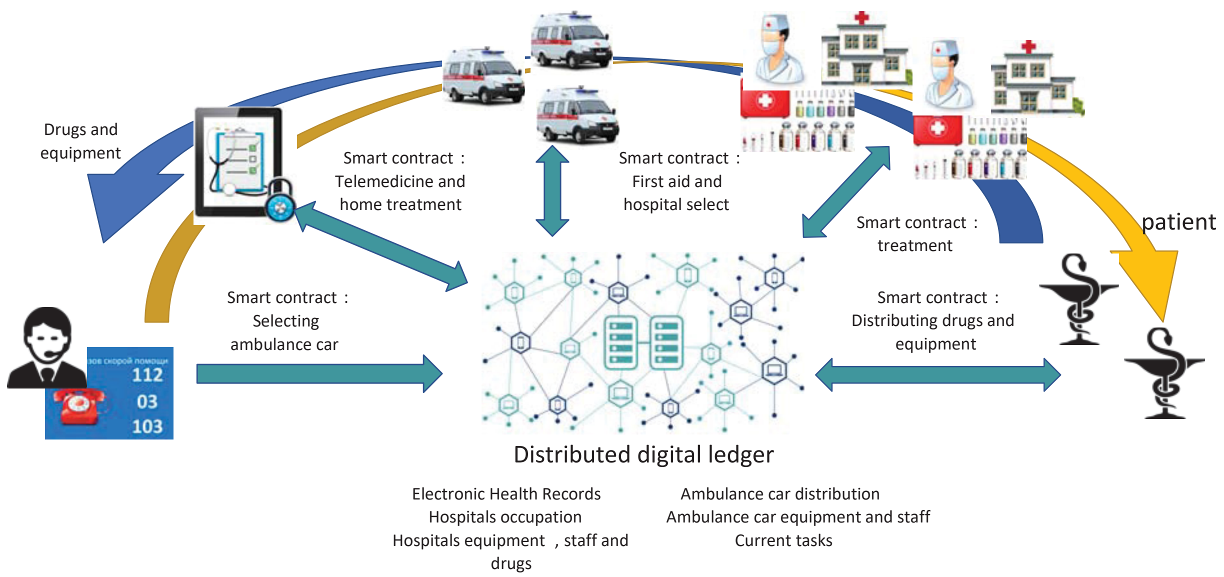

Fig. 1. Methodology of decision support on hospitalization

increase in the level of stress caused by the need for hospitalization.

It is proposed to use a mathematical formalism to describe human behavior. For example, in [41], a model of psychological factors of economic behavior is considered, which includes the systemic structure of an agent (person), presented in the work as a set of four interacting subsystems: intentional (reflects the agent's intentions), anticipatory (reflects the agent's expectations), cognitive (reflects the agent's perception of the surrounding world) and functional (reflects the agent's behavior). Analysis and compilation of behavior models are also used to predict human actions, for example, in tourism [42] and marketing [43]. In this case, the description can be based on various formalizations, for example, formulas of first-order logic, description logic, classical algebraic formulas, which are consistent with the proposed methodology.

In studies conducted in the context of the 2020 pandemic, it is noted that the incompleteness of a threatening situation has the main effect on people, and the cumulative nature of the stress effect is recorded [44]. Unfavorable background factors for all participants in the decision-making process are anxiety, fear of infection, forced isolation from family members [45], anxiety, and depressive states increase [8]. The behavior of patients is influenced by the stress, fear, depression caused by the disease itself and its severity; and by the stress associated, according to foreign scientists, with a “health crisis” [46], which is largely due to the dissemination of threatening, emotional, and sometimes redundant information about an invisible threat, which in isolation leads to the constant appeal of people to its sources, doubts that in these conditions one can count on a full and high-quality medical service. Lack of protective equipment, problems with adequate treatment, as well as a purely human factor - fatigue, tension, anxiety, and professional burnout of medical personnel [8],[47],[48], induce negative emotional states in hospitalized, attempts to influence the decisions of medical personnel.

Decision-making by medical workers, management personnel, operational workers is carried out against a background of fatigue, stress, and distress. The presence of professional stress, burnout, fear for one's life are confirmed in studies conducted in the PRC. In late January - early February 2020, doctors and nurses who worked with patients with COVID-19 reported symptoms of depression (50.4%), anxiety (44.6%), sleep disturbances (34%), and distress (71, five%). General patterns were identified, e.g. a greater intensity of symptoms was found by women compared to men and by nurses compared to other categories of health workers [48]. A high level of uncertainty, which causes stress:

a) expectations of negative consequences,
b) increased vigilance in relation to the threat,
c) false conclusions based on past experience,
d) lack of objective information and distrust of information sources,
e) loss of ability to realistically assess the situation, the presence of panic [44].

Uncertainty distress has become a key factor in the impact on medical staff in COVID-19 [49]. The uncertainty of the diagnosis and prognosis of treatment is associated with the lack of reliable and complete information about the disease and the forms of its manifestation, treatment methods, considering the individual characteristics of patients. These features of the diagnosis are the characteristic of the current situation of a pandemic, in which the diagnosis is not always defined timely, it is formulated vaguely and unclearly, the disease manifests itself variably, and a high variety of symptoms is demonstrated.

As several studies have shown [50], stress occurs when a person is sensitive to the perception of environmental stimuli, while her/his resources aimed at correcting the impact of the environment or changing it are insufficient. In the context of the ongoing pandemic, methods are being developed to express diagnostics of anxiety, states of uncertainty in large samples, and attempts are being made to assess the emotional state of individual social groups or society as a whole [51],[52].

Formalization of stress indicators requires high variability with the possibility of a fuzzy description of states. The most effective tool in this case is fuzzy sets. Within the framework of the methodology, fuzzy sets can be used together with the mathematical apparatus of fuzzy logic and fuzzy cooperative games, which provide not only the formalization of the state of the patient and doctors but also form constraints for the optimization problem being solved.

The use of fuzzy logic and fuzzy cooperative games in describing the interaction of coalition participants is a relatively new approach that has shown, however, its effectiveness in problems of supply chain configuration [53] and coalition formation [54]. From the medical point of view, the apparatus of fuzzy logic and cooperative games can be used to assess the effectiveness of hospitals [55]. The effectiveness in this work is assessed by a large number of parameters, including the number and quality of staff (doctors, nurses, support staff), the number of beds, the number of operations, costs of treatment and maintenance, etc. The mechanism of coalition games was used after the division of the country (in this study, Iran) into separate regions according to economic and demographic parameters, and the assumption that each hospital works in cooperation with other hospitals in the region. This allowed to calculate the total gain for the region and track the contribution of each hospital to the total gain.

When organizing the exchange of information within the framework of the methodology, it is proposed to use the capabilities of a distributed digital register. The rationale for this decision is the need to provide trusted access for various services to electronic health records to speed up the exchange of information about the patient's condition, to save the history of changes in the state. Using the smart contract mechanism, a distributed ledger can be configured to control access to electronic health records.

IV. Hospitalization process model

To formulate the hospitalization model when the first signs of pandemic are detected, an analysis of open sources and official documents of the Russian Ministry of Health was carried out.

According to the model, two related tasks can be distinguished that must be solved during the hospitalization process.

A. Task 1

The first task is to determine the need for hospitalization and the selection of the ambulance (Fig. 2).

Upon receipt of a call from a patient, a survey should be conducted with her/him to estimate the probability of a particular disease. The survey, in addition to questions to identify the main symptoms, may contain questions about concomitant diseases, gender, age, and recent contacts. Additionally, the location of the patient and his/her medical insurance is being specified.

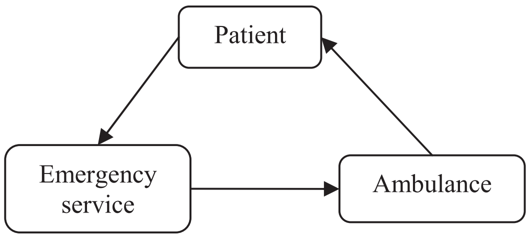

Fig. 2. Initial call dispatching problem

After collecting the information, the dispatcher service must quickly estimate the need for hospitalization (at least half of the symptoms of the disease has to be confirmed). Then, based on the current demand and availability, an ambulance is selected, which has the necessary equipment and medicines for preliminary examination and potential hospitalization.

As part of the developed methodology, dispatchers are offered a decision support system evaluating the need for hospitalization and selecting an appropriate ambulance. The set of parameters to be used for decision support includes:

Global parameters:

- Healthcare system priorities;
- General epidemiological situation.

Information gathered from the dispatcher:

- Number of calls for the period of a day;
- The average severity of patients who require hospitalization;
- The average distance from the patient's location to the hospital (ambulance service radius);
- Vacant beds in hospitals;
- Average queue time for ambulance appointments in case of hospitalization.

Information from ambulance cars:

- Location;
- Staff quality (Average decision time, number of errors (the patient returns to the place of residence);
- Ambulance equipment (medical drugs, tools, tests);
- Staff working time (fatigue level).

B. Task 2

The second task is to choose the hospital, the patient needs to be transported to (Fig. 3).

After an ambulance is assigned to a patient, the ambulance staff is responsible for the state of the patient. They need to conduct an initial examination using their own equipment and decide whether the patient needs urgent hospitalization or transportation to a sorting center or for additional testing. For example, in the case of COVID-19, computer tomography of the lungs may be necessary to confirm the diagnosis and the need for hospitalization.

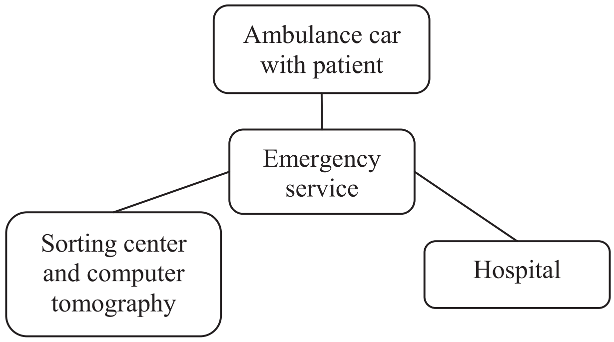

Fig. 3. Process of patient transportation to hospital

When deciding on hospitalization, it is necessary to choose a hospital that has vacant beds and all the necessary equipment to treat the patient with the given severity of the disease. For this purpose, it is also necessary to contact the dispatcher, who, based on the assessment of the current situation, decides on the place of additional examination or hospitalization.

When solving this problem, it is also necessary to take into account many parameters, including:

Patient and ambulance parameters:

- Patient condition (Condition description sheet (20 parameters and general assessment), comorbidities, age)
- Location

Dispatcher parameters:

- Healthcare system priorities
- Road traffic
- Sorting and laboratory center parameters
- Service time for one patient
- Service queue
- Availability of resources (tests, disinfectant materials)
- Free seats
- Cleaning and disinfection time after service

Hospital parameters:

- Service time for one patient
- Queue length
- Bed amount
- Available treatment protocols and scripts
- Availability of resources (medicines, equipment)

- Bed quality (availability of additional functions and/or equipment to ensure comfort and relief of the patient's condition)
- Staff qualification and competences

VII. Conclusion

Based on the results of the review and research, a methodology was formed to support decision-making on hospitalization in a pandemic. The methodology is based on an analysis of the current situation in the healthcare system, an assessment of the economic and social effects of hospitalization.

The methodology assumes the formalization of the process using an optimization problem that takes into account the main parameters of the system as the values of the objective function, and the limitations of the health care system as the limitations of the function. To take into account the economic effect and human behavior with an increase in the level of stress in the methodology, it is proposed to use the appropriate formalization for the mathematical description of these parameters and their consideration in the objective function using the apparatus of fuzzy logic.

For the exchange of data on the current situation, the use of a digital distributed ledger is proposed. The decision of the target function and decision making, in this case, can be implemented in the form of smart contracts in the registry. This approach ensures the consistency and immutability of data in the decision-making process and the accumulation of statistics for subsequent objective analysis of the pandemic.

Further areas of work are focused on formalizing the conditions and functions of constraints for the task and collecting operational information to determine significant parameters and refine the proposed formalization. Based on the results of formalization, it is planned to build a system that provides support for decision-making on hospitalization in a pandemic and check it taking into account the available data.

Acknowledgment

The reported study was funded by RFBR according to the research project № 20-04-60054 and by Russian State Research No. 0073-2019-0005.

References

[1] Rahman M M, Thill J-C and Paul K C 2020 COVID-19 Pandemic Severity, Lockdown Regimes, and People's Mobility: Early Evidence from 88 Countries *Sustainability* **12** 9101

[2] Patel U, Malik P, Mehta D, Shah D, Kelkar R, Pinto C, Suprun M, Dhamoon M, Hennig N and Sacks H 2020 Early epidemiological indicators, outcomes, and interventions of COVID-19 pandemic: A systematic review *Journal of global health* **10** 020506

[3] Walters E, Najmabadi S and Platoff E Texas hospitals are running out of drugs, beds, ventilators and even staff | The Texas Tribune

[4] Stewart W Dozens of ambulances filled with suspected coronavirus patients wait hours outside Moscow hospitals | Daily Mail Online

[5] Hendricks D With hospitals full of coronavirus patients, ambulances wait hours for beds to become available

[6] Yeo K T, Oei J L, De Luca D, Schmölzer G M, Guaran R, Palasanthiran P, Kumar K, Buonocore G, Cheong J, Owen L S, Kusuda S, James J, Lim G, Sharma A, Uthaya S, Gale C, Whittaker E, Battersby C, Modi N, Norman M, Naver L, Giannoni E, Diambomba Y, Shah P S, Gagliardi L, Harrison M, Pillay S, Alburaey A, Yuan Y and Zhang H 2020 Review of guidelines and recommendations from 17 countries highlights the challenges that clinicians face caring for neonates born to mothers with COVID-19 *Acta Paediatrica, International Journal of Paediatrics* **109** 2192–207

[7] Cabello I R, Echavez J F M, Serrano-Ripoll M J, Fraile-Navarro D, Roque M A F de, Moreno G P, Castro A, Perez I R, Campos R Z and Goncalves-Bradley D 2020 Impact of viral epidemic outbreaks on mental health of healthcare workers: a rapid systematic review *medRxiv* **4** 2020.04.02.20048892

[8] Montemurro N 2020 The emotional impact of COVID-19: From medical staff to common people *Brain, Behavior, and Immunity*

[9] Dalianis H 2018 *Clinical text mining: Secondary use of electronic patient records*

[10] Topol E J 2019 High-performance medicine: the convergence of human and artificial intelligence *Nature Medicine* **25** 44–56

[11] Yu K H, Beam A L and Kohane I S 2018 Artificial intelligence in healthcare *Nature Biomedical Engineering* **2** 719–31

[12] Cosoli G, Spinsante S and Scalise L 2020 Wrist-worn and chest-strap wearable devices: Systematic review on accuracy and metrological characteristics *Measurement: Journal of the International Measurement Confederation* **159**

[13] Zhong C L and Li Y le 2020 Internet of things sensors assisted physical activity recognition and health monitoring of college students *Measurement: Journal of the International Measurement Confederation* **159**

[14] Jamil F, Ahmad S, Iqbal N and Kim D H 2020 Towards a remote monitoring of patient vital signs based on iot-based blockchain integrity management platforms in smart hospitals *Sensors (Switzerland)* **20**

[15] Armitage H 2020 Stanford Medicine scientists hope to use data from wearable devices to predict illness, including COVID-19 | News Center | Stanford Medicine

[16] Radin J M, Wineinger N E, Topol E J and Steinhubl S R 2020 Harnessing wearable device data to improve state-level real-time surveillance of influenza-like illness in the USA: a population-based study *The Lancet Digital Health* **2** e85–93

[17] Lehne M, Sass J, Essenwanger A, Schepers J and Thun S 2019 Why digital medicine depends on interoperability *npj Digital Medicine* **2** 1–5

[18] Miñarro-Giménez J A, Cornet R, Jaulent M C, Dewenter H, Thun S, Gøeg K R, Karlsson D and Schulz S 2019 Quantitative analysis of manual annotation of clinical text samples *International Journal of Medical Informatics* **123** 37–48

[19] Anon UMLS Metathesaurus - MEDCIN (MEDCIN) - Synopsis

[20] Anon ICD-11

[21] Willyard B C 2019 Can AI Fix Medical Records ? unlock their potential

[22] Molano J I R, Lovelle J M C, Montenegro C E, Granados J J R and Crespo R G 2017 Metamodel for integration of Internet of Things, Social Networks, the Cloud and Industry 4.0 *Journal of Ambient Intelligence and Humanized Computing* **0** 0

[23] Bellavista P, Corradi A, Fanelli M and Foschini L 2012 A survey of context data distribution for mobile ubiquitous systems *ACM Computing Surveys* **44** 1–45

[24] Saggi M K and Jain S 2018 A survey towards an integration of big data analytics to big insights for value-creation *Information Processing and Management* **54** 758–90

[25] Ferreira L, Putnik G D, Lopes N, Lopes A and Cruz-Cunha M M 2015 A Cloud and Ubiquitous Architecture for Effective Environmental Sensing and Monitoring *Procedia Computer Science* **64** 1256–62

[26] Badii C, Bellini P, Cenni D, Difino A, Nesi P and Paolucci M 2017 Analysis and assessment of a knowledge based smart city architecture providing service APIs *Future Generation Computer Systems* **75** 14–29

[27] Cabrera O, Franch X and Marco J 2017 Ontology-based context modeling in service-oriented computing: A systematic mapping *Data and Knowledge Engineering* **110** 24–53

[28] Urbieta A, González-Beltrán A, Ben Mokhtar S, Anwar Hossain M and Capra L 2017 Adaptive and context-aware service composition for IoT-based smart cities *Future Generation Computer Systems* **76** 262–74

[29] Raskar R, Schunemann I, Barbar R, Vilcans K, Gray J, Vepakomma P, Kapa S, Nuzzo A, Gupta R, Berke A, Greenwood D, Keegan C, Kanaparti S, Beaudry R, Stansbury D, Arcila B B, Kanaparti R, Pamplona V, Benedetti F M, Clough A, Das R, Jain K, Louisy K,

Nadeau G, Pamplona V, Penrod S, Rajaee Y, Singh A, Storm G and Werner J 2020 Apps Gone Rogue: Maintaining Personal Privacy in an Epidemic
[30] Satamraju K P and Malarkodi B 2020 Proof of concept of scalable integration of internet of things and blockchain in healthcare *Sensors (Switzerland)* **20**
[31] Wang Z, Luo N and Zhou P 2020 GuardHealth: Blockchain empowered secure data management and Graph Convolutional Network enabled anomaly detection in smart healthcare *Journal of Parallel and Distributed Computing* **142** 1–12
[32] Wang S, Wang J, Wang X, Qiu T, Yuan Y, Ouyang L, Guo Y and Wang F Y 2018 Blockchain-Powered Parallel Healthcare Systems Based on the ACP Approach *IEEE Transactions on Computational Social Systems* **5** 942–50
[33] Islam A and Young Shin S 2020 A blockchain-based secure healthcare scheme with the assistance of unmanned aerial vehicle in Internet of Things *Computers and Electrical Engineering* **84** 106627
[34] Yong B, Shen J, Liu X, Li F, Chen H and Zhou Q 2020 An intelligent blockchain-based system for safe vaccine supply and supervision *International Journal of Information Management* **52** 102024
[35] British Medical Association 2020 COVID-19-ethical issues. A guidance note In brief
[36] Qiu Y Y, Wang S Q, Wang X L, Lu W X, Qiao D, Li J B, Gu Y Y, Zeng Y, Chen Y, Bai W Z, Xu B L and Han T W 2020 Epidemiological analysis on a family cluster of COVID-19 *Zhonghua liu xing bing xue za zhi = Zhonghua liuxingbingxue zazhi* **41** 506–9
[37] Gupta V and Ivanov D 2020 Dual sourcing under supply disruption with risk-averse suppliers in the sharing economy *International Journal of Production Research* **58** 291–307
[38] Keogh J G 2020 COVID-19: Rules of game must be changed to ensure supply of food - Food In Canada
[39] Linton, Tom Vakil B 2020 Coronavirus Is Proving We Need More Resilient Supply Chains
[40] Anon 2020 Coronavirus (COVID-19) Pandemic: Supply Chain Stabilization Task Force | FEMA.gov
[41] Kleiner G B, Rybachuk M A and Ushakov D V 2018 Psychological factors of economic behavior: a systemic view *Terra economicus* **16** 20–36
[42] Gretzel U, Werthner H, Koo C and Lamsfus C 2015 Conceptual foundations for understanding smart tourism ecosystems *Computers in Human Behavior* **50** 558–63
[43] Stalidis G, Karapistolis D and Vafeiadis A 2015 Marketing Decision Support Using Artificial Intelligence and Knowledge Modeling: Application to Tourist Destination Management *Procedia - Social and Behavioral Sciences* **175** 106–13
[44] Xiong J, Lipsitz O, Nasri F, Lui L M W, Gill H, Phan L, Chen-Li D, Iacobucci M, Ho R, Majeed A and McIntyre R S 2020 Impact of COVID-19 pandemic on mental health in the general population: A systematic review *Journal of Affective Disorders* **277** 55–64
[45] Shah K, Kamrai D, Mekala H, Mann B, Desai K and Patel R S 2020 Focus on Mental Health During the Coronavirus (COVID-19) Pandemic: Applying Learnings from the Past Outbreaks *Cureus*
[46] Garfin D R, Silver R C and Holman E A 2020 The novel coronavirus (COVID-2019) outbreak: Amplification of public health consequences by media exposure *Health psychology : official journal of the Division of Health Psychology, American Psychological Association* **39** 355–7
[47] Li W, Yang Y, Liu Z H, Zhao Y J, Zhang Q, Zhang L, Cheung T and Xiang Y T 2020 Progression of Mental Health Services during the COVID-19 Outbreak in China *International journal of biological sciences* **16** 1732–8
[48] Mo Y, Deng L, Zhang L, Lang Q, Liao C, Wang N, Qin M and Huang H 2020 Work stress among Chinese nurses to support Wuhan for fighting against the COVID-19 epidemic *Journal of Nursing Management*
[49] Freeston M, Tiplady A, Mawn L, Bottesi G and Thwaites S 2020 Towards a model of uncertainty distress in the context of Coronavirus (Covid-19)
[50] Buheji M, Jahrami H and Dhahi A S 2020 Minimising Stress Exposure During Pandemics Similar to COVID-19 *International Journal of Psychology and Behavioral Sciences* **2020** 9–16
[51] Ahorsu D K, Lin C Y, Imani V, Saffari M, Griffiths M D and Pakpour A H 2020 The Fear of COVID-19 Scale: Development and Initial Validation *International Journal of Mental Health and Addiction* 1–9
[52] Pakpour A H and Griffiths M D 2020 The fear of CoVId-19 and its role in preventive behaviors *Journal of Concurrent Disorders*
[53] Sheremetov L B 2009 A model of fuzzy coalition games in problems of configuring open supply networks *Journal of Computer and Systems Sciences International* **48** 765–78
[54] Mohebbi S and Li X 2015 Coalitional game theory approach to modeling suppliers' collaboration in supply networks *International Journal of Production Economics* **169** 333–42
[55] Omrani H, Shafaat K and Emrouznejad A 2018 An integrated fuzzy clustering cooperative game data envelopment analysis model with application in hospital efficiency *Expert Systems with Applications* **114** 615–28