Kołowrocki Krzysztof, 0000-0002-4836-4976
Gdynia Maritime University, Gdynia, Poland, k.kolowrocki{at}wn.umg.edu.pl
Bogalecka Magdalena, 0000-0002-8140-2620
Gdynia Maritime University, Gdynia, Poland, m.bogalecka{at}wznj.umg.edu.pl
Dąbrowska Ewa, 0000-0002-6704-9541
Gdynia Maritime University, Gdynia, Poland, e.dabrowska{at}wn.umg.edu.pl
Torbicki Mateusz, 0000-0003-4182-1932
Gdynia Maritime University, Gdynia, Poland, m.torbicki{at}wn.umg.edu.pl
Magryta-Mut Beata, 0000-0002-4189-1853
Gdynia Maritime University, Gdynia, Poland, b.magryta{at}wn.umg.edu.pl
Cichocka Oliwia, 0000-0002-7586-3009
Gdynia Maritime University, Gdynia, Poland, o.cichocka{at}wn.umg.edu.pl

Preliminary general approach to modelling COVID-19 pandemic sufferer safety impacted by human living conditions

Keywords

COVID-19, pandemic, human safety, modelling, identification, prediction, maintenance, optimization, consequences mitigation

Abstract

The safety and resilience indicators are proposed as crucial tools for analysis, identification, prediction and optimization of COVID-19 pandemic human safety and for minimization and mitigation of pandemic consequences.

1. Introduction

The methodology and preliminary general approach to Coronavirus disease 2019 (COVID-19) pandemic human safety and resilience analysis is proposed. The principles of multistate approach to COVID-19 pandemic human safety analysis are introduced. The methods and procedures are the authors' results (Bogalecka, 2020; Dąbrowska, 2020a-b; Kołowrocki, 2014; Kołowrocki & Kuligowska, 2018; Kołowrocki & Magryta, 2020a-b; Kołowrocki & Soszyńska-Budny, 2011/2015, 2017, 2018a-b; Kołowrocki et al., 2016; Magryta, 2020; Magryta-Mut, 2020; Torbicki & Drabiński, 2020), achieved in reliability and safety of complex systems and critical infrastructures (Lauge et al., 2015) preliminary modifications and transfers to pandemic human safety comprehensive analyse and they need further study and developments.
The proposed safety and resilience indicators are new original and crucial tools for analysis, identification, prediction and optimization of COVID-19 pandemic human safety and for minimization and mitigation of pandemic consequences that are presented as well. Based on the statistical data, the preliminary methods and approaches to identification of the unknown parameters of the proposed COVID-19 pandemic human safety models, the safety of the COVID-19 pandemic impacted by the human living condition change processes for various person kinds at their living areas are discussed as well.
The chapter is organised into 15 parts, including this Introduction as Section 1, Sections 2–14 and Conclusion as Section 15.

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In Section 2, the kinds of persons that can be infected by COVID-19 pandemic are defined through fixing their parameters and the ranges of values these parameters can assume. In Section 3, the stochastic human living condition change process of a fixed kind person at its living area is introduced and its parameters are defined through fixing their ranges of values. The human living condition change process is described by defining the human living condition states and fixing their number. Other parameters of the human living condition change process introduced in this section are the initial probabilities of this process at the particular human condition living states, the probabilities of transitions between the particular human condition living states, the distribution functions and the density functions of the conditional sojourn times at the living condition states and their mean values. Next, the basic human living condition change process characteristics, i.e. the unconditional mean values of the conditional sojourn times at the living condition states, the limit values of the human living condition change process transient probabilities at the particular living condition states and the human living condition change process total sojourn time at the particular living condition states during the fixed time, are determined. Section 4 is devoted to COVID-19 pandemic human safety. In this section there are introduced the notions of COVID-19 pandemic human safety basic indicators like, the COVID-19 pandemic human safety function, the person health risk function, the person health human fragility curve, the moment when the person health risk function exceeds a permitted level, the mean values of the person lifetimes in the health safety state subsets and the intensities of a person health degradation, i.e. the intensities of the person health departure from the health safety state subsets.

In Section 5, safety and resilience indicators for the COVID-19 pandemic sufferer are proposed in the case the person health is impacted by its outside conditions. The human safety of COVID-19 pandemic impacted by the human living condition change process of a fixed kind person at its living area is considered. The safety and resilience indicators of the fixed kind person COVID-19 pandemic related to the human living condition change process at its living area are proposed. The safety indicators introduced in Section 4 are modified and the coefficients of the outside conditions impact on the person health degradation and the person health degradation resilience indicators, i.e. the coefficients of the person health degradation resilience to its outside impacts are defined. Those COVID-19 pandemic human safety and resilience indicators are determined for the fixed kind person lifetimes in the safety state subsets having piecewise exponential safety functions. In Section 5, the cure and renewal of COVID-19 pandemic sufferer are discussed through the joining the results of previous sections with the results of the classical renewal theory and the indicators. This joining allow us to obtain the treatment (the renewal) and the ability to functioning in a health safety state subset of health not worse than a critical health safety state (the availability) characteristics for the treated sufferer with ignored (short) and non-ignored (long) time of treatment (renovation). In Section 7, the general model of COVID-19 pandemic consequences, including human activity threats and human activity degradation and losses, is proposed. The general approach to optimization of COVID-19 pandemic human safety is proposed in Section 8. The Section 9 is devoted to minimization and mitigation of COVID-19 pandemic consequences. In Section 10, a preliminary remarks on the identification methods of COVID-19 pandemic sufferer kind are done.

In Section 11, a preliminary approach to the identification of COVID-19 pandemic sufferer living conditions is proposed.

Section 12 proposes a preliminary approach to the identification of COVID-19 pandemic human safety. In Section 13, a preliminary suggestions on the identification of COVID-19 pandemic human activity threats are given. In Section 14, a preliminary approach to the identification of COVID-19 pandemic human activity degradation is proposed. In Section 15, the conclusions on the chapter context are done and the perspective for future research and cooperation with partners interested in this hot topic is formulated.

2. Kind of sufferer infected by COVID-19 pandemic

At the fixed area, we distinguish , $o \in \mathbb{N}$, parameters that define (describe) the kind of the person (the sufferer) infected by COVID-19 pandemic and mark the values these parameters can take by $v_1, v_2, \ldots, v_o$. Further, we assume that the possible values of the i-th parameter v_i, $i = 1,2,\ldots,o$, can belong to the interval $\langle e_i, f_i)$, $i = 1,2,\dots,o$. We divide each of the intervals $\langle e_i, f_i)$, $i = 1,2,\dots,o$, into m_i, $m_i \in \mathbb{N}$, disjoint subintervals

$$\langle e_{i1}, f_{i1}), \langle e_{i2}, f_{i2}), \dots, \langle e_{im_i}, f_{im_i}), \ i = 1,2,\dots,o,$$

such that

$$\langle e_{i1}, f_{i1}) \cup \langle e_{i2}, f_{i2}) \cup \dots \cup \langle e_{im_i}, f_{im_i}) = \langle e_i, f_i),$$

$$f_{ij_i} = e_{ij_i+1}, j_i = 1,2,\dots,m_i - 1, \ i = 1,2,\dots,o.$$

Thus, the points $(v_1, v_2, \dots, v_o)$ describing the values of the person parameters are the points from the set of the *o* dimensional space of the Cartesian product

$$\langle e_1, f_1) \times \langle e_2, f_2) \times \dots \times \langle e_o, f_o)$$

that is composed of the *o* dimensional space domains of the form

$$\langle e_{1j_1}, f_{1j_1}) \times \langle e_{2j_2}, f_{2j_2}) \times \dots \times \langle e_{oj_o}, f_{oj_o}),$$

where $j_i = 1,2,\dots,m_i$, $i = 1,2,\dots,o$, called the person kind and

$$v_i, \ i = 1,2,\dots,o,$$

can takes values from one of the intervals

$$\langle e_{i1}, f_{i1}), \langle e_{i2}, f_{i2}), \dots, \langle e_{im_i}, f_{im_i}),$$

$$i = 1,2,\dots,o.$$

The domains of the above form called the person kinds are numerated from 1 up to the value $v = m_1 \cdot m_2 \cdot \dots \cdot m_o$ that is the number of all possible sufferer kinds and marked by $k_1, k_2, \dots, k_v$. To define the particular kinds of sufferer infected by COVID-19 pandemic, it is necessary to introduce the order function given by

$$\mathrm{O}(j, o, [m_b]_{1\times o}, o) = \big((j-1) \bmod m_o\big) + 1,$$

$$j = 1,2,\dots,v,$$

and

$$\mathrm{O}(j, i, [m_b]_{1\times o}, o)$$

$$= \Big(\Big[j + 1 - \sum_{b=i+1}^{o}\Big((\mathrm{O}(j, b, [m_b]_{1\times o}, o) - 1) \cdot \prod_{l=b+1}^{o} m_l\Big)\Big] / \prod_{b=i+1}^{o} m_b\Big) \bmod m_i + 1,$$

$$j = 1,2,\dots,v, \ i = 1,2,\dots,o-1.$$

After that, the j-th person kind k_j, $j = 1,2,\dots,v$, is defined by intervals $\langle e_{i\,\mathrm{O}(j,i,[m_b]_{1\times o},o)}, f_{i\,\mathrm{O}(j,i,[m_b]_{1\times o},o)})$ assumed by values v_i, $i = 1,2,\dots,o$, of the person parameters i.e.

$$k_j: \{v_i \in \langle e_{i\,\mathrm{O}(j,i,[m_b]_{1\times o},o)}, f_{i\,\mathrm{O}(j,i,[m_b]_{1\times o},o)}),$$

$$i = 1,2,\dots,o\},$$

for $j = 1,2,\dots,v$.

3. Human living condition change process of sufferer at its living area

3.1. States of human living condition change process

At the fixed area, we distinguish , $a \in \mathbb{N}$, parameters that define (describe) the human living condition change process states at this area and mark the values they can take by $w_1, w_2, \dots, w_a$. Further, we assume that the possible values of the i-th parameter w_i, $i = 1,2,\dots,a$, can belong to the interval $\langle b_i, d_i)$, $i = 1,2,\dots,a$. We divide each of the intervals $\langle b_i, d_i)$, $i = 1,2,\dots,a$, into n_i, $n_i \in \mathbb{N}$, disjoint subintervals

$$\langle b_{i1}, d_{i1}), \langle b_{i2}, d_{i2}), \dots, \langle b_{im_i}, d_{im_i}), \ i = 1,2,\dots,a,$$

such that

$$\langle b_{i1}, d_{i1}) \cup \langle b_{i2}, d_{i2}) \cup \dots \cup \langle b_{in_i}, d_{in_i}) = \langle b_i, d_i),$$

$$d_{ij_i} = b_{ij_i+1}, j_i = 1,2,\dots,n_i - 1, \ i = 1,2,\dots,a.$$

Thus, the points $(w_1, w_2, \dots, w_a)$ describing the values of the human living condition parameters are the points from the set of the *a* dimensional space of the Cartesian product

$$\langle b_1, d_1) \times \langle b_2, d_2) \times \dots \times \langle b_a, d_a),$$

that is composed of the *a* dimensional space domains of the form

$\langle b_{1j_1}, d_{1j_1}\rangle \times \langle b_{2j_2}, d_{2j_2}\rangle \times \ldots \times \langle b_{aj_a}, d_{aj_a}\rangle,$

where $j_i = 1,2, \ldots n_i$, $i = 1,2, \ldots, a$, called the human living condition states and

$w_i, i = 1,2, \ldots, a,$

can takes values from one of the intervals

$\langle b_{i1}, d_{i1}\rangle, \langle b_{i2}, d_{i2}\rangle, \ldots, \langle b_{in_i}, d_{in_i}\rangle,$

$i = 1,2, \ldots, a.$

The domains of the above form called the human living condition states of the human living condition change process are numerated from 1 up to the value $w = n_1 \cdot n_2 \cdot \ldots \cdot n_a$ that is the number of all possible human living condition states and marked by $c_1, c_2, \ldots, c_w$.
To define the particular states of human living condition change process, it is necessary to introduce the order function given by

$$O(j, a, [n_b]_{1\times a}, a) = \big((j-1) \bmod n_a\big) + 1,$$

$j = 1,2, \ldots, w,$

and

$$O(j, i, [n_b]_{1\times a}, a)$$

$$= ([j + 1 - \textstyle\sum_{b=i+1}^{a}((O(j, b, [n_b]_{1\times a}, a) - 1) \cdot$$

$$\cdot \textstyle\prod_{l=b+1}^{a} n_l)]/\prod_{b=i+1}^{a} n_b) \bmod n_i + 1,$$

$j = 1,2, \ldots, w$, $i = 1,2, \ldots, a-1.$

After that, the j-th person kind c_j, $j = 1,2, \ldots, w$, is defined by intervals $\langle b_{i\,O(j,i,[n_b]_{1\times a},a)}$, $d_{i\,O(j,i,[n_b]_{1\times a},a)}\rangle$ assumed by values w_i, $i = 1,2, \ldots, a$, of the human living condition parameters i.e.

$$c_j : \{w_i \in \langle b_{i\,O(j,i,[n_b]_{1\times a},a)}, d_{i\,O(j,i,[n_b]_{1\times a},a)}\rangle,$$

$$i = 1,2, \ldots, a\},$$

for $j = 1,2, \ldots, w$.

3.2. Stochastic model of human living condition change process

To model the human living condition change process for the fixed person living area, we assume that the human living condition change process at this area is taking , $w \in \mathbb{N}$, different human living condition states $c_1, c_2, \ldots, c_w$. Further, we define the human living condition change process (t), $t \geq 0$, with discrete human living condition states from the set $\{c_1, c_2, \ldots, c_w\}$.
Assuming that the human living condition change process $L(t)$ is a semi-Markov process (Bogalecka, 2020; Dąbrowska, 2018; Grabski, 2015; Kołowrocki, 2014; Magryta, 2020) it can be described by the following human living condition change process parameters, that can be identified either statistically using the methods given in (Habibullah et al., 2009; Kołowrocki, 2014) or evaluated approximately by experts:

- the number of human living condition states w,
- the human living condition states

  $c_1, c_2, \ldots, c_w,$

- the vector

  $$[q_l(0)]_{1\times w} = [q_1(0), q_2(0), \ldots, q_w(0)]$$

  of the initial probabilities of the human living condition change process $L(t)$ staying at particular human living condition states c_l at the moment $t = 0$, where

  $$q_l(0) = P(L(0) = c_l), l = 1,2, \ldots, w,$$

- the matrix

  $$[q_{lk}]_{w\times w} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1w} \\ q_{21} & q_{22} & \cdots & q_{2w} \\ \vdots & \vdots & \ddots & \vdots \\ q_{w1} & q_{w2} & \cdots & q_{ww} \end{bmatrix} \quad (1)$$

  of probabilities of transition of the human living condition change process $L(t)$ between the human living condition states c_l and c_k

  $q_{lk}, l, k = 1,2, \ldots, w, l \neq k, q_{ll} = 0,$

  $l = 1,2, \ldots, w,$

- the matrix

$$[N_{lk}]_{w\times w} = \begin{bmatrix} N_{11} & N_{12} & \dots & N_{1w} \\ N_{21} & N_{22} & \dots & N_{2w} \\ \vdots & \vdots & \ddots & \vdots \\ N_{w1} & N_{w2} & \dots & N_{ww} \end{bmatrix}$$

  of mean values of the human living condition change process $L(t)$ conditional sojourn times L_{lk} at the human living condition state c_l when the next state is c_k

$$N_{lk} = E[L_{lk}] = \int_0^\infty t dL_{lk}(t) = \int_0^\infty t h_{lk}(t) dt,$$

$$l,k = 1,2,\dots,w,\ l \neq k,$$

$$N_{ll} = 0,\ l = 1,2,\dots,w, \quad (2)$$

  where

$$L_{lk}(t) = P(L_{lk} < t),\ t \geq 0,$$

$$l,k = 1,2,\dots,w,\ l \neq k,$$

  are conditional distribution functions of the human living condition change process $L(t)$, $t \geq 0$, conditional sojourn times L_{lk} at the human living condition states corresponding to conditional density functions

$$h_{lk}(t) = \frac{dC_{lk}(t)}{dt},\ t \geq 0,$$

$$l,k = 1,2,\dots,w,\ l \neq k.$$

Assuming that we have identified the above parameters of the human living condition change process semi-Markov model, we can predict this process basic characteristics, that can be either calculated analytically or evaluated approximately by experts (Dąbrowska, 2020a-b; Kołowrocki, 2014; Kołowrocki et al., 2016; Torbicki & Drabiński, 2020):

- the vector

$$[N_l]_{1\times w} = [N_1, N_2, \dots, N_w] \quad (3)$$

  of mean values of the human living condition change process $L(t)$, $t \geq 0$, unconditional sojourn times L_l, $l = 1,2,\dots,w$, at the human living condition states c_l, $l = 1,2,\dots,w$,

$$N_l = E[L_l] = \sum_{k=1}^{w} q_{lk} N_{lk},\ l = 1,2,\dots,w, \quad (4)$$

  where q_{lk} are defined by (1) and N_{lk} are defined by the formula (2),
- the vector

$$[q_l]_{1\times w} = [q_1, q_2, \dots, q_w]$$

  of limit values of the human living condition change process $L(t)$, $t \geq 0$, transient probabilities

$$q_l(t) = P(L(t) = c_l),\ t \geq 0,\ l = 1,2,\dots,w,$$

  at the particular human living condition states, determined by

$$q_l = \lim_{t\to\infty} q_l(t) = \frac{\pi_l N_l}{\sum_{k=1}^{w} \pi_k N_k},$$

$$l = 1,2,\dots,w, \quad (5)$$

  where N_l, $l = 1,2,\dots,w$, are given by (4), while the steady probabilities π_l of the vector $[\pi_l]_{1\times w}$ satisfy the system of equations

$$\begin{cases} [\pi_l]_{1\times w} = [\pi_l]_{1\times w} \cdot [q_{lk}]_{w\times w} \\ \sum_{k=1}^{w} \pi_k = 1. \end{cases} \quad (6)$$

In the case of a periodic human living condition change process, the limit transient probabilities q_l, $l = 1,2,\dots,w$, at the human living condition states determined by (5), are the long term proportions of the human living condition change process $L(t)$, $t \geq 0$, sojourn times at the particular human living condition states c_l, $l = 1,2,\dots,w$. Another interesting characteristic of the human living condition change process $L(t)$, $t \geq 0$, possible to obtain is the vector of the mean values

$$[\hat{N}_l]_{1\times w} = \hat{N}_1, \hat{N}_2, \dots, \hat{N}_w],$$

of the total sojourn times $\hat{L}_l$, $l = 1,2,\dots,w$, of the human living condition change process $L(t)$ at the particular human living condition states c_l, $l = 1,2,\dots,w$, during the fixed time L. It is well known (Kołowrocki, 2014; Kołowrocki et al., 2016), that the human living condition change process total sojourn times $\hat{L}_l$ at the particular human living condition states c_l for sufficiently large time L have approximately normal distributions with the mean values given by

$$\hat{N}_l = E[\hat{C}_l] = q_l L, \, l = 1,2,\dots,w, \qquad (7)$$

where q_l are given by (5).

4. COVID-19 pandemic human health safety

In the multistate safety analysis to define the COVID-19 pandemic human health safety with degrading health safety states of a sufferer (without considering its treatment), we assume that:

- the person have the health safety state set $\{0,1,\dots,z\}$, $z \ge 1$,
- the health safety states are ordered, the health safety state 0 is the worst (the sufferer is dead directly because of COVID-19 pandemic) and the health safety state z is the best (the person is completely free of COVID-19 symptoms),
- r, $r \in \{1,2,\dots,z\}$, is the critical health safety state (the person health state characterized by dangerous COVID-19 symptoms, it means that the person staying in the health safety states less than this health safety state is highly dangerous for himself and for other persons within his living area),
- $T(u)$, $u = 1,2,\dots,z$, is a random variable representing the lifetime of the person in the health safety state subset $\{u, u+1,\dots,z\}$, $u = 1,2,\dots,z$, while it was in the health safety state z at the moment $t = 0$,
- the health safety states degrade with time t, $t \ge 0$,
- $s(t)$, $t \ge 0$, is the person health safety state at the moment t, $t \ge 0$, given that it was in the health safety state z at the moment $t = 0$.

The above assumptions mean that the health safety states of the person/the sufferer may be changed in time only from better to worse. The way in which the person health safety states change is illustrated in Figures 1-2.

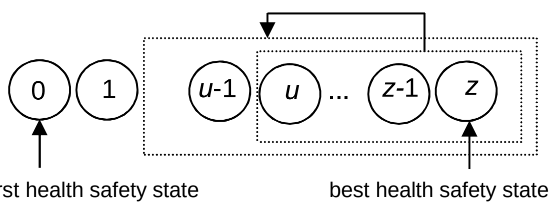

Figure 1. Illustration of a person health safety states changing.

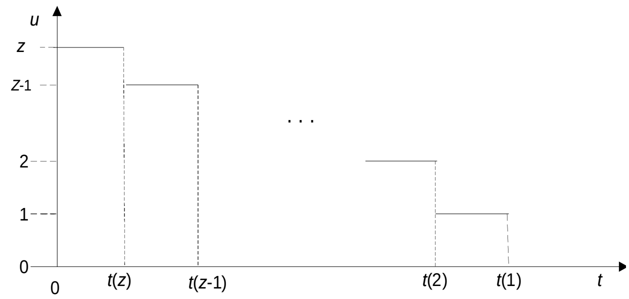

Figure 2. The relationship between the realizations $t(u)$, $u = 1,2,\dots,z$, of the person lifetimes $T(u)$, $u = 1,2,\dots,z$, in the health safety state subsets $\{u, u+1,\dots,z\}$, $u = 1,2,\dots,z$.

We denote by $T(u)$, $u = 1,2,\dots,z$, the person lifetime in the safety health state subset $\{u, u+1,\dots,z\}$, $u = 1,2,\dots,z$, and we define the person health safety function by the vector

$$\boldsymbol{S}(t,\cdot) = [\boldsymbol{S}(t,1), \boldsymbol{S}(t,2),\dots,\boldsymbol{S}(t,z)], \, t \ge 0, \qquad (8)$$

where

$$\boldsymbol{S}(t,u) = P(s(t) \ge u | s(0) = z)$$

$$= P(T(u) > t), \, t \ge 0, u = 1,2,\dots,z, \qquad (9)$$

is the probability that the person is in the health safety state subset $\{u, u+1,\dots z\}$, $u = 1,2,\dots,z$, at the moment t, $t \ge 0$, while it was in the health safety state z at the moment $t = 0$.

The human health safety functions $\boldsymbol{S}(t,u)$, $t \ge 0$, $u = 1,2,\dots,z$, defined by (9) are called the coordinates of the person health safety function $\boldsymbol{S}(t,\cdot)$, $t \ge 0$, given by (8). Thus, the relationship between the distribution function $\boldsymbol{F}(t,u)$, $t \ge 0$, $u = 1,2,\dots,z$, of the person lifetime $T(u)$, $u = 1,2,\dots,z$, in the health safety state subset $\{u, u+1,\dots,z\}$, $u = 1,2,\dots,z$, and defined by (9) the coordinate $\boldsymbol{S}(t,u)$, $t \ge 0$, $u = 1,2,\dots,z$, of its health safety function (8) is given by

$$\boldsymbol{F}(t,u) = P(T(u) \le t) = 1 - P(T(u) > t)$$

$$= 1 - \boldsymbol{S}(t,u), \, t \ge 0, u = 1,2,\dots,z.$$

The exemplary graph of a person five-state ($z = 4$) health safety function

$$\boldsymbol{S}(t,\cdot) = [\boldsymbol{S}(t,1), \boldsymbol{S}(t,2), \boldsymbol{S}(t,3), \boldsymbol{S}(t,4)],$$

is shown in Figure 3.

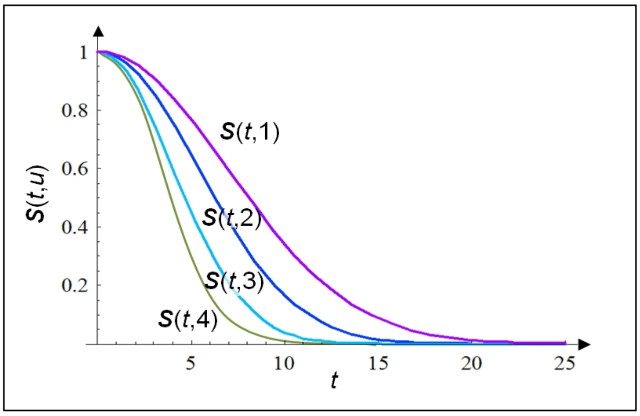

Figure 3. The graphs of a person five-state health safety function $\boldsymbol{S}(t,\cdot)$ coordinates.

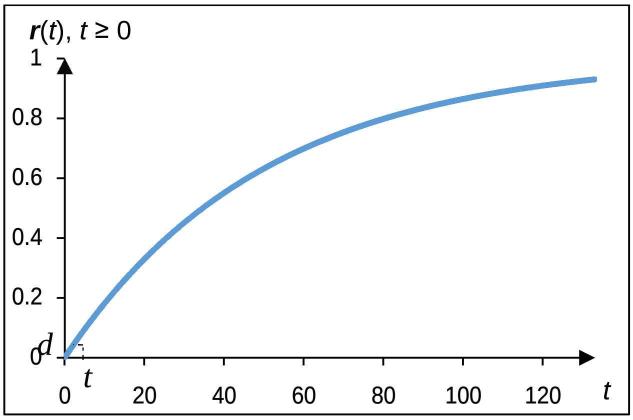

Figure 4. The graph of the exemplary person health risk function $\boldsymbol{r}(t)$ (the fragility curve).

If r is the critical health safety state, then the person health risk function

$$\boldsymbol{r}(t) = P(s(t) < r | s(0) = z)$$

$$= P(T(r) \leq t), t \geq 0, \quad (10)$$

is defined as a probability that the person health is in the subset of health safety states worse than the critical health safety state r, $r \in \{1,\ldots,z\}$ while it was in the best health safety state z at the moment $t = 0$ and given by

$$\boldsymbol{r}(t) = 1 - \boldsymbol{S}(t,r), \ t \geq 0, \quad (11)$$

where $\boldsymbol{S}(t,r)$, $t \geq 0$, is the coordinate of the person health safety function given by (9) for $u = r$.

The graph of the exemplary person health risk function , also called the fragility curve (Gouldby et al., 2010), is presented in Figure 4.

The moment t, when the person health function exceeds a permitted level d, $d \in (0,1)$, is defined by

$$\boldsymbol{\tau} = \boldsymbol{r}^{-1}(\delta), \quad (12)$$

where $\boldsymbol{r}^{-1}(t)$, $t \geq 0$, is the inverse function of the risk function $\boldsymbol{r}(t)$, $t \geq 0$, given by (11).

The mean values of the person lifetimes in the health safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, are defined by

$$\boldsymbol{\mu}(u) = \int_0^\infty [\boldsymbol{S}(t,u)]dt, u = 1,2,\ldots,z, \quad (13)$$

where $(t,u), t \geq 0$, $u = 1,2,\ldots,z$, are the coordinates of the person health safety function (8) given by (9).

The intensities of a person health degradation, i.e. the intensities of the person health departure from the health safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, are defined by

$$\boldsymbol{\lambda}(t,u) = \frac{-\frac{d\boldsymbol{S}(t,u)}{dt}}{\boldsymbol{S}(t,u)}, t \geq 0, u = 1,2,\ldots,z, \quad (14)$$

where $\boldsymbol{S}(t,u), t \geq 0, u = 1,2,\ldots,z$, are the coordinate of the person health safety function (8) given by (9).

In the case, when the sufferer lifetimes in the safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, have piecewise exponential safety functions, i.e. the coordinates $\boldsymbol{S}(t,u)$, $t \geq 0$, $u = 1,2,\ldots,z$, of the person health safety function (9) are given by

$$\boldsymbol{S}(t,u) = \exp[-\boldsymbol{\lambda}(u)t], t \geq 0,$$

$$\boldsymbol{\lambda}(u) \geq 0, u = 1,2,\ldots,z, \quad (15)$$

where $\boldsymbol{\lambda}(u)$, $u = 1,2,\ldots,z$, are the intensities of a person health degradation, i.e. the intensities of the person health departure from the health safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, the above defined by (10)–(14) the human health safety indicators take the following forms:

- the person health risk function

$$\boldsymbol{r}(t) = 1 - \exp[-\boldsymbol{\lambda}(r)t], t \geq 0,$$

$$\boldsymbol{\lambda}(r) \geq 0, \quad (16)$$

- the moment t, when the person health risk function exceeds a permitted level d, $d \in (0,1)$

$$\boldsymbol{\tau} = -\frac{1}{\boldsymbol{\lambda}(r)} ln(1-\delta), \quad (17)$$

- the mean values of the person lifetimes in the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$,

$$\boldsymbol{\mu}(u) = \frac{1}{\boldsymbol{\lambda}(u)}, u = 1,2,\ldots,z, \quad (18)$$

- the intensities of a person health degradation, i.e. the intensities of the person health departure from the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$,

$$\boldsymbol{\lambda}(u) = \frac{1}{\boldsymbol{\mu}(u)}, u = 1,2,\ldots,z, \quad (19)$$

where (u), $u = 1,2,\ldots,z$, are the mean values of the person lifetimes in the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$.
Moreover in the case the person health is impacted by outside conditions, the following resilience indicators can be defined,

- the coefficients of the outside conditions impact on the person health degradation

$$\boldsymbol{\rho}(t,u) = \frac{\boldsymbol{I\lambda}(u)}{\boldsymbol{\lambda}(u)} = \frac{\boldsymbol{\mu}(u)}{\boldsymbol{I\mu}(u)}, u = 1,2,\ldots,z, \quad (20)$$

where $\boldsymbol{\lambda}(u)$ and $\boldsymbol{I\lambda}(u)$, $u = 1,2,\ldots,z$, respectively are the intensities of person health degradation without and with outside impacts, determined respectively according to (14) and (33) or (19) and (41), $\boldsymbol{\mu}(u)$ and $\boldsymbol{I\mu}(u)$, $u = 1,2,\ldots,z$, respectively are the mean values of the person lifetimes in the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$, without and with outside impacts, determined according to (13) and (31) or (18) and (39),

- the person health degradation resilience indicators, i.e. the coefficients of the person health degradation resilience to its outside impacts

$$\boldsymbol{RI}(t,u) = \frac{1}{\boldsymbol{\rho}(t,u)}, \ t \geq 0, u = 1,2,\ldots,z, \quad (21)$$

where $\boldsymbol{\rho}(t,u)$, $u = 1,2,\ldots,z$, are the coefficients of the impact on the person health degradation defined by (20).

5. Safety and resilience of COVID-19 pandemic sufferer impacted by human living conditions at its living area

We denote by $[T(u)]^{(l)}$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, the person conditional lifetime in the health safety state subset $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$, while the human living condition change process $L(t)$, $t \geq 0$, at the person living area is at the human living condition safety state c_l, $l = 1,2,\ldots,w$, and the conditional person health safety function of the person related to the human living condition change process $L(t)$, $t \geq 0$, at its living area by the vector

$$[\boldsymbol{S}(t,\cdot)]^{(l)}$$

$$= [[\boldsymbol{S}(t,1)]^{(l)}, [\boldsymbol{S}(t,2)]^{(l)}, \ldots, [[\boldsymbol{S}(t,z)]^{(l)}],$$

$$t \geq 0, l = 1,2,\ldots,w, \quad (22)$$

with the coordinates defined by

$$[\boldsymbol{S}(t,u)]^{(l)} = P([T(u)]^{(l)} > t | L(t) = c_l),$$

$$t \geq 0, u = 1,2,\ldots,z, l = 1,2,\ldots,w. \quad (23)$$

The safety function $[\boldsymbol{S}(t,u)]^{(l)}$, $t \geq 0$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, is the conditional probability that the person conditional lifetime $[T(u)]^{(l)}$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, in the health safety state subset $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$, is greater than t, $t \geq 0$, while the human living condition change process at its living area $L(t)$, $t \geq 0$, is at the human living condition state c_l, $l = 1,2,\ldots,w$.
Next, we denote by $IT(u)$, $u = 1,2,\ldots,z$, the unconditional lifetime in the health safety state subset $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$, of the person impacted by the human living condition change process $L(t)$, $t \geq 0$, and the unconditional person health safety function of the person impacted by the human living condition change process $L(t)$, $t \geq 0$, by the vector

$$\boldsymbol{IS}(t,\cdot) = [\boldsymbol{IS}(t,1), \boldsymbol{IS}(t,2), \ldots, \boldsymbol{IS}(t,z)], \quad (24)$$

for $t \geq 0$, with the coordinates defined by

$$\boldsymbol{IS}(t,u) = P(IT(u) > t), t \geq 0,$$

$u = 1,2,\ldots,z.$ (25)

In the case when the person living time L at the fixed living area is large enough, the coordinates of the unconditional person health safety function related to the human living condition change process $L(t)$, $t \geq 0$, defined by (25), are evaluated by

$$\boldsymbol{IS}(t,u) \cong \sum_{l=1}^{w} q_l[\boldsymbol{S}(t,u)]^{(l)}, t \geq 0,$$

$$u = 1,2,\ldots,z, \quad (26)$$

where $[\boldsymbol{S}(t,u)]^{(l)}$, $t \geq 0$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, are the coordinates of the conditional person health safety function related to the human living condition change process $L(t)$, $t \geq 0$, defined by (22)–(23) and q_l, $l = 1,2,\ldots,w$, at human living condition change process $L(t)$, $t \geq 0$, limit transient probabilities at the human living condition states c_l, $l = 1,2,\ldots,w$, given by (25).

If r is the person health critical safety state, then the second person health safety indicator impacted by the human living condition change process $L(t)$, $t \geq 0$, the person health risk function

$$\boldsymbol{Ir}(t) = P(s(t) < r | s(0) = z)$$

$$= P(IT(r) \leq t), t \geq 0, \quad (27)$$

is defined as a probability that the person health impacted by the human living condition change process $L(t)$, $t \geq 0$, is in the subset of health safety states worse than the critical health safety state r, $r \in \{1,\ldots,z\}$, while it was in the best health safety state z at the moment $t = 0$ and given by

$$\boldsymbol{Ir}(t) = 1 - \boldsymbol{IS}(t,r), t \geq 0, \quad (28)$$

where $\boldsymbol{IS}(t,r)$, $t \geq 0$, is the coordinate of the unconditional person health safety function related to the human living condition change process $L(t)$, $t \geq 0$, given by (26) for $u = r$.

The graph of the person health risk function $\boldsymbol{Ir}(t)$, $t \geq 0$, defined by (28), is the person health safety indicator called the fragility curve of the person impacted by the human living condition change process $L(t)$, $t \geq 0$.

Other practically useful safety and resilience indicators of the person health safety impacted by the human leaving condition change process $L(t)$, $t \geq 0$, at its living area, are:

- the moment of exceeding an acceptable value of the person impacted by the human living condition change process health risk function level d given by

$$\boldsymbol{I\tau} = \boldsymbol{Ir}^{-1}(\delta), \quad (29)$$

where $\boldsymbol{Ir}^{-1}(t)$, $t \geq 0$, is the inverse function of the person health risk function $\boldsymbol{Ir}(t)$, $t \geq 0$, given by (28),

- the mean lifetimes of the person impacted by the human living condition change process lifetimes in the health safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, given by

$$\boldsymbol{I\mu}(u) = \int_0^{\infty}[\boldsymbol{IS}(t,u)]dt \cong \sum_{l=1}^{w} q_l[\boldsymbol{\mu}(u)]^{(l)},$$

$$u = 1,2,\ldots,z, \quad (30)$$

where $[\boldsymbol{\mu}(u)]^{(l)}$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, are the mean values of the person conditional lifetimes $[T(u)]^{(l)}$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, in the health safety state subsets $\{u, u+1,\ldots,z\}$ at the human living condition state c_l, $l = 1,2,\ldots,w$, given by

$$[\boldsymbol{\mu}(u)]^{(l)} = \int_0^{\infty}[\boldsymbol{S}(t,u)]^{(l)}dt,$$

$$u = 1,2,\ldots,z, l = 1,2,\ldots,w, \quad (31)$$

and $[\boldsymbol{S}(t,u)]^{(l)}$, $t \geq 0$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, are defined by (23) and q_l, $l = 1,2,\ldots,w$, are given by (5),

- the mean lifetimes $\boldsymbol{I\bar{\mu}}(u)$, $u = 1,2,\ldots,z$, of the person impacted by the human living condition change process lifetimes in the particular health safety states are given by

$$\boldsymbol{I\bar{\mu}}(u) = \boldsymbol{I\mu}(u) - \boldsymbol{I\mu}(u+1),$$

$$u = 0,1,\ldots,z-1, \boldsymbol{I\bar{\mu}}(z) = \boldsymbol{I\mu}(z), \quad (32)$$

where $\boldsymbol{I\mu}(u)$, $u = 1,2,\ldots,z$, are given by (30),

- the intensities of health degradation of the person impacted by the human living condition change process / the intensities of the person impacted by the human living condition change process departure from the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$,

$$\boldsymbol{I\lambda}(t,u) = \frac{-\frac{d\boldsymbol{IS}(t,u)}{dt}}{\boldsymbol{IS}(t,u)},\ t \geq 0,\ u = 1,2,\ldots,z, \quad (33)$$

- the coefficients of the human living condition change process impact on the person health intensities of degradation / the coefficients of the human living condition change impact on the person health intensities of departure from the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$,

$$\boldsymbol{I\rho}(t,u) = \boldsymbol{I\lambda}(t,u)/\boldsymbol{\lambda}(t,u),\ t \geq 0,$$

$$u = 1,2,\ldots,z, \quad (34)$$

where $\boldsymbol{\lambda}(t,u)$, $t \geq 0$, $u = 1,2,\ldots,z$, are the intensities of degradation of the person health without of human living condition change process impact defined by (14) and $\boldsymbol{I\lambda}(t,u)$, $t \geq 0$, $u = 1,2,\ldots,z$, are the intensities of degradation of the person health impacted by the human living condition change process, defined by (33),

- the resilience indicators of the person health to human living condition change process impact are defined by

$$\boldsymbol{IRI}(t,u) = 1/\boldsymbol{I\rho}(t,u),\ t \geq 0,$$

$$u = 1,2,\ldots,z, \quad (35)$$

where $\boldsymbol{I\rho}(t,u)$, $t \geq 0$, $u = 1,2,\ldots,z$, are the coefficients of the human living condition change process impact on the person health intensities of degradation given by (34).

In the case, the fixed kind person conditional lifetimes in the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$, have piecewise exponential health safety functions, i.e. the coordinate $[\boldsymbol{S}(t,u)]^{(l)}$, $t \geq 0$, $u = 1,2,\ldots,z$, defined by (23), of the person health safety function (22) are given by

$$[\boldsymbol{S}(t,u)]^{(l)} = \exp[-[\boldsymbol{\lambda}(u)]^{(l)}t],\ [\boldsymbol{\lambda}(u)]^{(l)} \geq 0,$$

$$t \geq 0,\ u = 1,2,\ldots,z,\ l = 1,2,\ldots,w,$$

where $[\boldsymbol{\lambda}(u)]^{(l)}$, $u = 1,2,\ldots,z$, $l = 1,2,\ldots,w$, are the person health impacted by the human living condition change process intensities of degradation at the human living condition states c_l, $l = 1,2,\ldots,w$, the above defined indicators take the following forms:

- the coordinates of the unconditional person health safety function of the person impacted by the human living condition change process $L(t)$, $t \geq 0$,

$$\boldsymbol{IS}(t,u) \cong \sum_{l=1}^{w} q_l \exp[-[\boldsymbol{\lambda}(u)]^{(l)}t],\ t \geq 0,$$

$$u = 1,2,\ldots,z, \quad (36)$$

- the person health risk function

$$\boldsymbol{Ir}(t) \cong 1 - \sum_{l=1}^{w} q_l \exp[-[\boldsymbol{\lambda}(r)]^{(l)}t],$$

$$t \geq 0, \quad (37)$$

- the moment of exceeding an acceptable value of the person impacted by the human living condition change process health risk function level *d* given by the value of the inverse to risk function $\boldsymbol{Ir}(t)$, given by (37) for *t* = *d*

$$\boldsymbol{I\tau} = \left(1 - \sum_{l=1}^{w} q_l \exp[-[\boldsymbol{\lambda}(r)]^{(l)}(\cdot)]\right)^{-1}(\delta), \quad (38)$$

- the mean lifetimes of the person impacted by the human living condition change process lifetimes in the health safety state subsets $\{u, u+1, \ldots, z\}$, $u = 1,2,\ldots,z$, given by

$$\boldsymbol{I\mu}(u) \cong \sum_{l=1}^{w} \frac{q_l}{[\boldsymbol{\lambda}(u)]^{(l)}},\ u = 1,2,\ldots,z, \quad (39)$$

- the mean lifetimes $\boldsymbol{I\bar{\mu}}(u)$, $u = 1,2,\ldots,z$, of the person impacted by the human living condition change process lifetimes in the particular health safety states are given by

$$\boldsymbol{I\bar{\mu}}(u) = \sum_{l=1}^{w} q_l \cdot \left(\frac{1}{[\boldsymbol{\lambda}(u)]^{(l)}} - \frac{1}{[\boldsymbol{\lambda}(u+1)]^{(l)}}\right),$$

$$u = 0,1,\ldots,z-1,$$

$$\boldsymbol{I\bar{\mu}}(z) = \sum_{l=1}^{w} \frac{q_l}{[\boldsymbol{\lambda}(z)]^{(l)}}, \quad (40)$$

- the intensities of health degradation of the person impacted by the human living condition change process

$$\boldsymbol{I\lambda}(t,u) = \frac{\sum_{l=1}^{w} q_l [\boldsymbol{\lambda}(u)]^{(l)} \exp[-[\boldsymbol{\lambda}(u)]^{(l)} t]}{\sum_{l=1}^{w} q_l \exp[-[\boldsymbol{\lambda}(u)]^{(l)} t]},$$

$$t \geq 0, u = 1,2,\dots,z, \quad (41)$$

- the coefficients of the human living condition change process impact on the person health intensities of degradation

$$\boldsymbol{I\rho}(t,u) = \frac{\sum_{l=1}^{w} q_l [\boldsymbol{\lambda}(u)]^{(l)} \exp[-([\boldsymbol{\lambda}(u)]^{(l)}) t]}{\boldsymbol{\lambda}(u) \sum_{l=1}^{w} q_l \exp[-[\boldsymbol{\lambda}(u)]^{(l)} t]},$$

$$t \geq 0, u = 1,2,\dots,z, \quad (42)$$

where $\boldsymbol{\lambda}(u), u = 1,2,\dots,z$, are the intensities of health degradation of the person without impact of the human living condition change process,

- the resilience indicators of the person health to human living condition change process impact are defined by

$$\boldsymbol{IRI}(t,u) = \frac{\boldsymbol{\lambda}(u) \sum_{l=1}^{w} q_l \exp[-[\boldsymbol{\lambda}(u)]^{(l)} t]}{\sum_{l=1}^{w} q_l [\boldsymbol{\lambda}(u)]^{(l)} \exp[-([\boldsymbol{\lambda}(u)]^{(l)}) t]},$$

$$t \geq 0, u = 1,2,\dots,z, \quad (43)$$

where $\boldsymbol{\lambda}(u)$, $u = 1,2,\dots,z$, are the intensities of health degradation of the person without impact of the human living condition change process.

6. Treatment and renewal of COVID-19 pandemic sufferer

The models and methods presented in previous sections can by applied for determining the safety indicators of COVID-19 pandemic sufferer at variable human living operation conditions in the case when it is non-treated (non-renewed). Joining these results and the results of the classical renewal theory it is possible to obtain the treatment (the renewal) and the ability to function in a health safety state subset of health not worse than a critical health safety state (the availability) characteristics for the treated sufferer with ignored (short) and non-ignored (long) time of treatment (renovation). In this section, there are determined the distributions, the expected values and the variances of the times until the successive exceeding the critical health safety state and the distributions, the expected values and the variances of the numbers of exceeding the critical health safety state at a fixed moment of time for the considered kind of COVID-19 pandemic sufferers in the case when they are treated (renewed) and the time of their treatment (renovation) is ignored. There are also determined the distribution functions, the expected values and the variances of the times until the successive renovations and the distribution functions, the expected values and the variances of the times until the successive exceeding the critical health safety state and the distributions, the expected values and variances of the numbers of renovations up to a fixed moment of time and the distributions, the expected values and variances of the numbers of exceeding the critical health safety state up to a fixed moment of time, the steady availability coefficients and the availability coefficients in a fixed time interval for the considered COVID-19 pandemic sufferers in the case when they are treated (renewed) and the time of their treatment (renovation) is non-ignored.

6.1. COVID-19 pandemic sufferer with ignored time of renovation

We assume here that the considered COVID-19 pandemic sufferers after exceeding the critical health safety state are renewed that the time of their renovation is very small in comparison to their lifetimes in the health safety state subsets not worse than the critical health safety state and we may omit it. Under this assumption, it is possible to obtain the results for the renowned COVID-19 pandemic sufferers with ignored time of renovation formulated in the following proposition (Kołowrocki & Soszyńska-Budny, 2011/2015).

Proposition 6.1

If the COVID-19 pandemic sufferer with ignored time of renovation have the piecewise exponential person health safety function defined by (24)–(25) with the coordinates given by (36) at the human living condition states c_l, $l = 1,2,\dots,w$, and the critical health safety state is $r, r \in \{1,2,\dots,z\}$, then:

a) the time $S_N(r)$, until the N-th exceeding by the COVID-19 sufferer the critical health safety state r, for sufficiently large N, has approximately normal distribution

$N\left(N\mu(r), \sqrt{N}\sigma(r)\right)$, i.e. its distribution function is given by

$$F^{(N)}(t,r) = P(S_N(r) < t)$$

$$\cong F_{N(0,1)}\left(\frac{t-N\mu(r)}{\sqrt{N}\sigma(r)}\right),$$

$$t \geq 0, r \in \{1,2,\ldots,z\}, \quad (44)$$

b) the expected value and the variance of the time $S_N(r)$ until the N-th exceeding by the COVID-19 sufferer the critical health safety state r, for sufficiently large N, are respectively given by

$$E[S_N(r)] \cong N\mu(r), Var[S_N(r)] \cong N\sigma^2(r),$$

$$r \in \{1,2,\ldots,z\}, \quad (45)$$

c) the number $N(t,r)$ of exceeding by the COVID-19 sufferer the critical health safety state r up to the moment t, $t \geq 0$, for sufficiently large t, has approximately normal distribution of the form

$$P(N(t,r) = N)$$

$$\cong F_{N(0,1)}\left(\frac{(N+1)\mu(r)-t}{\sigma(r)\sqrt{\frac{t}{\mu(r)}}}\right) - F_{N(0,1)}\left(\frac{N\mu(r)-t}{\sigma(r)\sqrt{\frac{t}{\mu(r)}}}\right),$$

$$t \geq 0, N = 0,1,..., r \in \{1,2,\ldots,z\}, \quad (46)$$

d) the expected value and the variance of the number $N(t,r)$ of exceeding by the COVID-19 sufferer the critical health safety state r up to the moment t, $t \geq 0$, for sufficiently large t, are respectively given by

$$H(t,r) \cong \frac{t}{\mu(r)}, Var(t,r) \cong \frac{t}{\mu^3(r)}\sigma^2(r), t \geq 0,$$

$$r \in \{1,2,\ldots,z\}, \quad (47)$$

where $\mu(r)$ and $\sigma(r)$ are given by:

$$\mu(r) = \sum_{l=1}^{w} q_l \frac{1}{\lambda^{(l)}(r)}, \quad (48)$$

$$\sigma^2(r) = \int_0^{+\infty} 2t\boldsymbol{IS}(t,r)dt - [\mu(r)]^2, \quad (49)$$

where $\boldsymbol{IS}(t,r)$ is given by (36) for $u = r$, $r \in \{1,2,\ldots,z\}$.

6.2. COVID-19 pandemic sufferer with non-ignored time of renovation

We assume here that the considered COVID-19 pandemic sufferers after exceeding the critical health safety state are renewed and that the time of their renovation is not very small in comparison to their lifetimes in the health safety state subsets not worse than the critical health safety state and we may not omit it. Under this assumption, it is possible to obtain the results formulated in the following proposition (Kołowrocki & Soszyńska-Budny, 2011/2015).

Proposition 6.2

If the COVID-19 pandemic sufferer with non-ignored time of renovation have the piecewise exponential person health safety function defined by (24)–(25) with the coordinates given by (36) at the human living condition states c_l, $l = 1,2,\ldots,w$, and the critical health safety state is r, $r \in \{1,2,\ldots,z\}$, and the successive times of the COVID-19 pandemic sufferer renovation are independent and have an identical distribution function with the expected value $\mu_o(r)$ and the variance $\sigma_o^2(r)$, then:

a) the time $\bar{S}_N(r)$ until the N-th exceeding by the COVID-19 pandemic sufferer the critical health safety state r, for sufficiently large N, has approximately normal distribution

$$N(N\mu(r) + (N-1)\mu_o(r)),$$

$$\sqrt{N\sigma^2(r) + (N-1)\sigma_o^2(r)}),$$

i.e. its distribution function is given by

$$\bar{F}^{(N)}(t,r) = P(\bar{S}_N(r) < t)$$

$$\cong F_{N(0,1)}\left(\frac{t-N\left(\mu(r)+\mu_o(r)\right)+\mu_o(r)}{\sqrt{N\left(\sigma^2(r)+\sigma_o^2(r)\right)-\sigma_o^2(r)}}\right), t \geq 0,$$

$$r \in \{1,2,\ldots,z\}, \quad (50)$$

b) the expected value and the variance of the time $\bar{S}_N(r)$ until the N-th exceeding by the COVID-19 pandemic sufferer the critical health safety state r, for sufficiently large N, are respectively given by

$$E[\bar{S}_N(r)] \cong N\mu(r) + (N-1)\mu_o(r),$$

$$Var[\bar{S}_N(r)] \cong N\sigma^2(r) + (N-1)\sigma_o^2(r),$$

$$r \in \{1,2,\ldots,z\}, \quad (51)$$

c) the number $\bar{N}(t,r)$, $t \geq 0$, of exceeding by the COVID-19 pandemic sufferer the critical health safety state *r* up to the moment *t*, $t \geq 0$, for sufficiently large *t*, has approximately distribution of the form

$$P(\bar{N}(t,r) = N)$$

$$\cong F_{N(0,1)}\left(\frac{(N+1)(\mu(r)+\mu_o(r))-t-\mu_0(r)}{\sqrt{\frac{t+\mu_0(r)}{\mu(r)+\mu_0(r)}(\sigma^2(r)+\sigma_o^2(r))}}\right)$$

$$-F_{N(0,1)}\left(\frac{N(\mu(r)+\mu_o(r))-t-\mu_0(r)}{\sqrt{\frac{t+\mu_0(r)}{\mu(r)+\mu_0(r)}(\sigma^2(r)+\sigma_o^2(r))}}\right), t \geq 0,$$

$$N = 0,1,\ldots, r \in \{1,2,\ldots,z\}, \quad (52)$$

d) the expected value and the variance of the number $\bar{N}(t,r), t \geq 0$, of exceeding by the COVID-19 pandemic sufferer the critical health safety state r, up to the moment t, $t \geq 0$, for sufficiently large *t*, are respectively given by

$$\bar{H}(t,r) \cong \frac{t+\mu_0(r)}{\mu(r)+\mu_o(r)}, t \geq 0,$$

$$\bar{D}^2(t,r) \cong \frac{t+\mu_0(r)}{(\mu(r)+\mu_o(r))^3}\left(\sigma^2(r) + {\sigma_o}^2(r)\right),$$

$$t \geq 0, r \in \{1,2,\ldots,z\}, \quad (53)$$

e) the time $\bar{\bar{S}}_N(r)$ until the *N*-th COVID-19 pandemic sufferer renovation, for sufficiently large *N*, has approximately normal distribution

$$N(N(\mu(r) + \mu_o(r)), \sqrt{N(\sigma^2(r) + \sigma_o^2(r))}),$$

i.e. its distribution function is given by

$$\bar{\bar{F}}^{(N)}(t,r) = P(\bar{\bar{S}}_N(r) < t)$$

$$\cong F_{N(0,1)}\left(\frac{t-N(\mu(r)+\mu_o(r))}{\sqrt{N(\sigma^2(r)+\sigma_o^2(r))}}\right), t \geq 0,$$

$$r \in \{1,2,\ldots,z\}, \quad (54)$$

f) the expected value and the variance of the time $\bar{\bar{S}}_N(r)$ until the *N*-th COVID-19 pandemic sufferer's renovation, for sufficiently large *N*, are respectively given by

$$E[\bar{\bar{S}}_N(r)] \cong N(\mu(r) + \mu_o(r)),$$

$$Var[\bar{\bar{S}}_N(r)] \cong N(\sigma^2(r) + \sigma_o^2(r)),$$

$$r \in \{1,2,\ldots,z\}, \quad (55)$$

g) the number $\bar{\bar{N}}(t,r)$, $t \geq 0$, of the COVID-19 pandemic sufferer's renovations up to the moment t, $t \geq 0$, for sufficiently large *t*, has approximately distribution of the form

$$P(\bar{\bar{\bar{N}}}(t,r) = N)$$

$$\cong F_{N(0,1)}\left(\frac{(N+1)(\mu(r)+\mu_o(r))-t}{\sqrt{\frac{t}{\mu(r)+\mu_0(r)}(\sigma^2(r)+\sigma_o^2(r))}}\right)$$

$$-F_{N(0,1)}\left(\frac{N(\mu(r)+\mu_o(r))-t}{\sqrt{\frac{t}{\mu(r)+\mu_0(r)}(\sigma^2(r)+\sigma_o^2(r))}}\right), t \geq 0,$$

$$N = 0,1,\ldots, r \in \{1,2,\ldots,z\}, \quad (56)$$

h) the expected value and the variance of the number $\bar{\bar{N}}(t,r)$, $t \geq 0$, of the COVID-19 pandemic sufferer's renovations up to the moment t, $t \geq 0$, for sufficiently large *t*, are respectively given by

$$\bar{\bar{H}}(t,r) \cong \frac{t}{\mu(r)+\mu_o(r)},$$

$$\bar{\bar{D}}^2(t,r) \cong \frac{t}{(\mu(r)+\mu_o(r))^3}(\sigma^2(r) + {\sigma_o}^2(r)),$$

$$r \in \{1,2,\ldots,z\}, \quad (57)$$

i) the steady availability coefficient of the COVID-19 pandemic sufferer at the moment t, $t \geq 0$, for sufficiently large *t*, is given by

$$A(t,r) \cong \frac{\mu(r)}{\mu(r)+\mu_o(r)}, t \geq 0, r \in \{1,2,\ldots,z\}, \quad (58)$$

j) the steady availability coefficient of the COVID-19 pandemic sufferer's in the time interval $\langle t, t+\tau)$, $t \geq 0$, $\tau > 0$, for sufficiently large t, is given by

$$A(t,\tau,r) \cong \frac{1}{\mu(r)+\mu_o(r)} \int_\tau^\infty \boldsymbol{IS}(t,r)dt,$$

$$t \geq 0, \tau > 0, r \in \{1,2,\dots,z\}, \quad (59)$$

where $\mu(r)$ and $\sigma(r)$ are given respectively by (48)–(49) and $\boldsymbol{IR}(t,r)$, $t \geq 0$, is given by (36) for $u = r$.

7. General model of pandemic consequences

7.1. Modelling process of human activity threats

To model the process of human activity threats caused by the COVID-19 pandemic, we fix the time interval from 0 until t, $t \geq 0$ as the time of a COVID-19 pandemic duration and we distinguish ε, $\varepsilon \in \mathbb{N}$, kinds of human activity threats as the consequences of the COVID-19 pandemic human safety exceeding the critical health safety state ***r*** is defined in Section 4. Next, we suppose that these threats may cause the human activity degradation (disintegration) and we mark them by $E^1, E^2, \dots, E^\varepsilon$. Further, we introduce the set of vectors

$$E = \{e: e = [e^1, e^2, \dots, e^\varepsilon], e^i \in \{0,1\}\}, \quad (60)$$

where

$$e^i = \begin{cases} 1, & \text{if a human activity threat } E^i \text{ occurs} \\ 0, & \text{if a human activity threat } E^i \text{ does not occur} \end{cases}$$

for $i = 1,2,\dots,\varepsilon$. We call vectors (60) the state of human activity threats.

We may eliminate vectors that cannot occur and we number the remaining states of the set E from $b = 1$ up to ω, $\omega \in \mathbb{N}$, where ω is the number of different elements of the set

$$E = \{e_1, e_2, \dots, e_\omega\},$$

where

$$e_b = [e_b^1, e_b^2, \dots, e_b^\varepsilon], b = 1,2,\dots,\omega,$$

and $e_b^i \in \{0,1\}$, $i = 1,2,\dots,\varepsilon$.

Next, we can define the process of human activity threats $E(t)$, $t \geq 0$, with its discrete states from the set,

$$E = \{e_1, e_2, \dots, e_\omega\}.$$

After that, we assume a semi-Markov model (Grabski, 2015; Kołowrocki 2014; Kołowrocki & Soszyńska-Budny, 2011/2015; Limnios & Oprisan, 2005; Macci, 2008; Mercier, 2008) of the process of human activity threats $E(t)$, $t \geq 0$ and denote by θ_{bd} its random conditional sojourn time at the state e_b while its next transition will be done to the state e_d, $b, d = 1,2,\dots,\omega$, $b \neq d$. This way, the process of human activity threats $E(t)$, $t \geq 0$ can be described by:

- the vector of the probabilities

  $$\zeta_b(0) = P(E(0) = e_b), b = 1,2,\dots,\omega,$$

  of its initial states at the moment $t = 0$

  $$[\zeta_b(0)]_{1\times\omega} = [\zeta_1(0), \zeta_2(0), \dots, \zeta_\omega(0)],$$

- the matrix of probabilities of transitions between the states e_b and e_d, $b, d = 1,2,\dots,\omega$, $b \neq d$,

  $$[\zeta_{bd}]_{\omega\times\omega} = \begin{bmatrix} \zeta_{11} & \zeta_{12} & \cdots & \zeta_{1\omega} \\ \zeta_{21} & \zeta_{22} & \cdots & \zeta_{2\omega} \\ \vdots & \vdots & \ddots & \vdots \\ \zeta_{\omega 1} & \zeta_{\omega 2} & \cdots & \zeta_{\omega\omega} \end{bmatrix}, \quad (61)$$

  where by formal agreement

  $$\forall b = 1,2,\dots,\omega, \zeta_{bb} = 0,$$

- the matrix

  $$[\Psi_{bd}]_{\omega\times\omega} = \begin{bmatrix} \Psi_{11} & \Psi_{12} & \cdots & \Psi_{1\omega} \\ \Psi_{21} & \Psi_{22} & \cdots & \Psi_{2\omega} \\ \vdots & \vdots & \ddots & \vdots \\ \Psi_{\omega 1} & \Psi_{\omega 2} & \cdots & \Psi_{\omega\omega} \end{bmatrix},$$

  of mean values of conditional sojourn times

  $$\Psi_{bd} = E[\xi_{bd}] = \int_0^\infty t dG_{bd}(t) \int_0^\infty t g_{bd}(t) dt,$$

  $$b, d = 1,2,\dots,\omega, b \neq d, \quad (62)$$

where by formal agreement

$\forall b = 1,2,\ldots,\omega, \Psi_{bb}(t) = 0,$

where

$G_{bd}(t) = P(\xi_{bd} < t), t \geq 0,$

$b, d = 1,2,\ldots,\omega, b \neq d,$

are conditional distribution functions of the process $E(t)$, $t \geq 0$, conditional sojourn times ξ_{bd} at the states of human activity threats corresponding to conditional density functions

$g_{bd}(t) = \frac{dG_{bd}(t)}{dt}, t \geq 0,$

$b, d = 1,2,\ldots,\omega, b \neq d.$

From the formula for total probability, it follows that the unconditional distribution functions of the sojourn times ξ_b, $b = 1,2,\ldots,\omega$, of the process of human activity threats (t), $t \geq 0$, at the states e_b, $b = 1,2,\ldots,\omega$, are determined by (Kołowrocki & Soszyńska-Budny, 2011/2015)

$G_b(t) = \sum_{d=1}^{\omega} \zeta_{bd} G_{bd}(t), b = 1,2,\ldots,\omega.$

Hence, the mean values of the process of human activity threats $E(t)$, $t \geq 0$, unconditional sojourn times ξ_b, $b = 1,2,\ldots,\omega$, at the states are given by

$$\Psi_b = E[\xi_b] = \sum_{d=1}^{\omega} \zeta_{bd} \Psi_{bd}, b = 1,2,\ldots,\omega, \quad (63)$$

where Ψ_{bd} are given by (51).
The limit values of the process of human activity threats $E(t)$, $t \geq 0$, transient probabilities at the particular states

$\zeta_b(t) = P(E(t) = e_b), t \geq 0,$

$$b = 1,2,\ldots,\omega, \quad (64)$$

are given by (Kołowrocki & Soszyńska-Budny, 2011/2015)

$\zeta_b = \lim_{t\to+\infty} \zeta_b(t) = \frac{\pi_b \Psi_b}{\sum_{d=1}^{\omega} \pi_d \Psi_d},$

$$b = 1,2,\ldots,\omega, \quad (65)$$

where Ψ_b are given by (63), while the steady probabilities π_b of the vector $[\pi_b]_{1\times\omega}$ satisfy the system of equations

$$\begin{cases} [\pi_b] = [\pi_b][\zeta_{bd}] \\ \sum_{d=1}^{\omega} \pi_d = 1 \end{cases},$$

and $[\zeta_{bd}]_{\omega\times\omega}$ is given by (61).
The asymptotic distribution of the sojourn total time $\hat{\xi}_b$ of the process of human activity threats $E(t)$ in the time interval $\langle 0, \xi \rangle$, $\xi > 0$, at the state e_b is normal with the expected value

$$\hat{\Psi}_b = E[\hat{\xi}_b] \cong \zeta_b \xi, b = 1,2,\ldots,\omega, \quad (66)$$

where ζ_b are given by (65).

7.2. Modelling process of human activity degradation

The particular states of the process of human activity threats $E(t)$, $t \geq 0$, may lead to dangerous effects degrading the human activity. To construct the general model of human activity degradation caused by the process of human activity threats by the COVID-19 pandemic and exceeding the critical health safety state, we distinguish the set of δ, $\delta \in \mathbb{N}$, kinds of parameters that define (describe) the human activity degradation as the effects of human activity threats observed when the COVID-19 pandemic human safety exceed the critical health safety state *r*, defined in Section 4. We mark the values they can take by $\varpi_1, \varpi_2, \ldots, \varpi_\delta$.
Further, we assume that the possible values of the *i*-th parameter ϖ_i, $i = 1,2,\ldots,\delta$, can belong to the interval $\langle e_i, f_i)$, $i = 1,2,\ldots,\delta$. We divide each of the intervals $\langle e_i, f_i)$, $i = 1,2,\ldots,\delta$, into v_i, $v_i \in \mathbb{N}$, disjoint subintervals

$\langle e_{i1}, f_{i1}), \langle e_{i2}, f_{i2}), \ldots, \langle e_{iv_i}, f_{iv_i}), i = 1,2,\ldots,\delta,$

such that

$\langle e_{i1}, f_{i1}) \cup \langle e_{i2}, f_{i2}) \cup \ldots \cup \langle e_{iv_i}, f_{iv_i}) = \langle e_i, f_i),$

$f_{ir_i} = e_{ir_i+1}, \; r_i = 1,2,\ldots,v_i - 1, \; i = 1,2,\ldots,\delta.$

Thus, the points $(\varpi_1, \varpi_2, \ldots, \varpi_\delta)$ describing the values of the human activity degradation parameters are the points from the set of the *d* dimensional space of the Cartesian product

$\langle e_1, f_1) \times \langle e_2, f_2) \times \ldots \times \langle e_\delta, f_\delta),$

that is composed of the d dimensional space domains of the form

$\langle e_{1r_1}, f_{1r_1}) \times \langle e_{2r_2}, f_{2r_2}) \times \ldots \times \langle e_{\delta r_\delta}, f_{\delta r_\delta}),$

where $r_i = 1,2, \ldots v_i$, $i = 1,2, \ldots, \delta$, called the human activity degradation states and
ϖ_i, $i = 1,2, \ldots, \delta$,
can takes values from one of the intervals

$\langle e_{i1}, f_{i1}), \langle e_{i2}, f_{i2}), \ldots, \langle e_{iv_i}, f_{iv_i}), \ i = 1,2, \ldots, \delta.$

The domains of the above form called the human activity degradation states of human activity degradation process are numerated from 1 up to the value $\varpi = v_1 \cdot v_2 \cdot \ldots \cdot v_\delta$ that is the number of all possible states of human activity degradation and marked by $r_1, r_2, \ldots, r_\varpi$.
To define the particular human activity degradation states, it is necessary to introduce the order function given by

$$\mathrm{O}(j, \delta, [v_b]_{1\times\delta}, \delta) = \big((j-1) \bmod v_o\big) + 1,$$

$$j = 1,2, \ldots, \varpi,$$

and

$$\mathrm{O}(j, i, [v_b]_{1\times\delta}, \delta)$$

$$= ([j + 1 - \textstyle\sum_{b=i+1}^{\delta}((\mathrm{O}(j, b, [v_b]_{1\times\delta}, \delta) - 1) \cdot$$

$$\cdot \textstyle\prod_{l=b+1}^{\delta} v_l)] / \prod_{b=i+1}^{\delta} v_b) \bmod v_i \ + 1,$$

$$j = 1,2, \ldots, \varpi, \ \ i = 1,2, \ldots, \delta - 1.$$

After that, the j-th human activity degradation state r_j, $j = 1,2, \ldots, \varpi$, is defined by intervals $\langle e_{i\,\mathrm{O}(j,i,[v_b]_{1\times\delta},\delta)}, f_{i\,\mathrm{O}(j,i,[v_b]_{1\times\delta},\delta)})$ assumed by values ϖ_i, $i = 1,2, \ldots, \delta$, of the human activity degradation parameters i.e.

$$r_j\colon \{\varpi_i \in \langle e_{i\,\mathrm{O}(j,i,[v_b]_{1\times\delta},\delta)}, f_{i\,\mathrm{O}(j,i,[v_b]_{1\times\delta},\delta)}),$$

$$i = 1,2, \ldots, \delta\},$$

for $j = 1,2, \ldots, \varpi$.

Next, we defined the proces of human activity degradation $R(t)$, $t \geq 0$, with its discrete states from the set

$$R = \{r_1, r_2, \ldots, r_\varpi\},$$

where $r_m \neq r_n$ for $m, n = 1,2, \ldots, \varpi$.
Next, to involve the process of human activity degradation $R(t)$, $t \geq 0$, with process of human activity threats $E(t)$, we introduced the function

$$R^{(b)}(t),\ t \geq 0,\ b = 1,2, \ldots, \omega,$$

depending on the states e_b, $b = 1,2, \ldots, \omega$, of the process of human activity threats $E(t)$, $t \geq 0$, and taking its values in the set of human activity degradation states R. This function is called the conditional process of human activity degradation, while the process of human activity threats $E(t)$, $t \geq 0$, is at the state e_b, $b = 1,2, \ldots, \omega$.
We assume a semi-Markov model (Grabski, 2015; Kołowrocki, 2014; Kołowrocki & Soszyńska-Budny, 2011/2015; Limnios & Oprisan, 2005; Macci, 2008; Mercier, 2008) of the process $R^{(b)}(t)$, $t \geq 0$, $b = 1,2, \ldots, \omega$, and denote by $\eta_{mn}^{(b)}$, its random conditional sojourn times at the state $r_m^{(b)}$ while its next transition will be done to the state $r_n^{(b)}$, $m, n = 1,2, \ldots, \varpi$, $m \neq n$, $b = 1,2, \ldots, \omega$.
The process of human activity degradation $R^{(b)}(t)$ is defined by:

- the vector of probabilities

  $$p_m^{(b)}(0) = P\big(R(0) = r_m^{(b)}\big),$$

  $$m = 1,2, \ldots, \varpi,\ b = 1,2, \ldots, \omega,$$

  of its initial states at the moment $t = 0$

  $$\big[p_m^{(b)}(0)\big]_{1\times\varpi} = \big[p_1^{(b)}(0), p_2^{(b)}(0), \ldots, p_\varpi^{(b)}(0)\big],$$

- the matrix of probabilities of transitions between the states $r_m^{(b)}$ and $r_n^{(b)}$, $m, n = 1,2, \ldots, \varpi$, $m \neq n$, $b = 1,2, \ldots, \omega$,

$$\big[p_{mn}^{(b)}\big]_{\varpi\times\varpi} = \begin{bmatrix} p_{11}^{(b)} & p_{12}^{(b)} & \cdots & p_{1\varpi}^{(b)} \\ p_{21}^{(b)} & p_{22}^{(b)} & \cdots & p_{2\varpi}^{(b)} \\ \vdots & \vdots & \ddots & \vdots \\ p_{\varpi 1}^{(b)} & p_{\varpi 2}^{(b)} & \cdots & p_{\varpi\varpi}^{(b)} \end{bmatrix}, \qquad (67)$$

where $p_{mm}^{(b)} = 0$ for $m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$,

- the matrix

$$\left[M_{mn}^{(b)}\right]_{\varpi\times\varpi} = \begin{bmatrix} M_{11}^{(b)} & M_{12}^{(b)} & \dots & M_{1\varpi}^{(b)} \\ M_{21}^{(b)} & M_{22}^{(b)} & \dots & M_{2\varpi}^{(b)} \\ \vdots & \vdots & \ddots & \vdots \\ M_{\varpi 1}^{(b)} & M_{\varpi 2}^{(b)} & \dots & M_{\varpi\varpi}^{(b)} \end{bmatrix},$$

of mean values of conditional sojourn times

$$M_{mn}^{(b)} = E\left[\eta_{mn}^{(b)}\right]$$

$$= \int_0^\infty t dH_{mn}^{(b)}(t) = \int_0^\infty t h_{mn}^{(b)}(t)dt, \quad (68)$$

$m, n = 1,2,\dots,\varpi$, $m \neq n$, $b = 1,2,\dots,\omega$,

where by formal agreement

$\forall m = 1,2,\dots,\varpi$, $M_{mm}^{(b)} = 0$,

where

$H_{mn}^{(b)}(t) = P\left(\eta_{mn}^{(b)} < t\right)$, $t \geq 0$, $m, n = 1,2,\dots,\varpi$,

$m \neq n$, $b = 1,2,\dots,\omega$,

are conditional distribution functions of the process $R^{(b)}(t), t \geq 0$, conditional sojourn times $\eta_{mn}^{(b)}$ at the states of human activity degradation $r_m^{(b)}$ corresponding to conditional density functions

$h_{mn}^{(b)}(t) = \frac{dH_{mn}^{(b)}(t)}{dt}$, $t \geq 0$, $m, n = 1,2,\dots,\varpi$,

$m \neq n$, $b = 1,2,\dots,\omega$.

From the formula for total probability, it follows that the unconditional distribution functions of the sojourn times $\eta_m^{(b)}$, $m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$, of the process of human activity degradation $R^{(b)}(t)$, $t \geq 0$, at the states $r_m^{(b)}$, $m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$ are determined by (Kołowrocki & Soszyńska-Budny, 2011/2015)

$H_m^{(b)}(t) = \sum_{n=1}^{\varpi} p_{mn}^{(b)} H_{mn}^{(b)}(t)$, $m = 1,2,\dots,\varpi$,

$b = 1,2,\dots,\omega$,

Hence, the mean values $E\left[\eta_m^{(b)}\right]$ of the process of human activity degradation $R^{(b)}(t)$, $t \geq 0$, unconditional sojourn times $\eta_m^{(b)}$, $m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$ at the states are given by

$$M_m^{(b)} = E\left[\eta_m^{(b)}\right] = \sum_{n=1}^{\varpi} p_{mn}^{(b)} M_{mn}^{(b)}, \quad (69)$$

$m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$,

where $M_{mn}^{(b)}$ are given (68).

The limit values of the process of human activity degradation $R^{(b)}(t), t \geq 0$, transient probabilities at the particular states

$p_m^{(b)}(t) = P\left(R^{(b)}(t) = r_m^{(b)}\right)$, $t \geq 0$,

$m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$ (70)

are given by (Kołowrocki & Soszyńska-Budny, 2011/2015)

$$p_m^{(b)} = \lim_{t\to+\infty} p_m^{(b)}(t) = \frac{\pi_m^{(b)} M_m^{(b)}}{\sum_{n=1}^{\varpi} \pi_n^{(b)} M_n^{(b)}}, \quad (71)$$

$m = 1,2,\dots,\varpi$, $b = 1,2,\dots,\omega$,

where $M_m^{(b)}$ are given by (69), while the steady probabilities $\pi_m^{(b)}$ of the vector $\left[\pi_m^{(b)}\right]_{1\times\varpi}$ satisfy the system of equations

$$\begin{cases} \left[\pi_m^{(b)}\right] = \left[\pi_m^{(b)}\right]\left[p_{mn}^{(b)}\right] \\ \sum_{n=1}^{\varpi} \pi_n^{(b)} = 1, \end{cases}$$

and $\left[p_{mn}^{(b)}\right]_{\varpi\times\varpi}$ is given by (67).

The asymptotic distribution of the sojourn total time $\hat{\eta}_m^{(b)}$, of the process of human activity degradation $R^{(b)}(t)$, $t \geq 0$, in the time interval $\langle 0, \eta \rangle$, $\eta > 0$, at the state $r_m^{(b)}$ is normal with the expected value

$$\widehat{M}_m^{(b)} = E\left[\hat{\eta}_m^{(b)}\right] \cong p_m^{(b)} \eta, \quad (72)$$

where $p_m^{(b)}$ are given by (71).

Thus, according to the formula for total probability and (64) and (70), the probabilities

$p_m(t) = P(R(t) = r_m),$

$t \geq 0, m = 1,2,\ldots,\varpi,$

are defined by

$p_m(t)$

$= \sum_{b=1}^{\omega} P\,(E(t) = e_b) \cdot (R(t) = r_m | E(t) = e_b)$

$= \sum_{b=1}^{\omega} \zeta_b(t) \cdot p_m^{(b)}(t), m = 1,2,\ldots,\varpi,$

and according to (54) and (60) their limit forms are

$$p_m = \sum_{b=1}^{\omega} \zeta_b \cdot p_m^{(b)}, m = 1,2,\ldots,\varpi. \quad (73)$$

Hence, the sojourn total time $\hat{\eta}_m$ of the unconditional process of human activity degradation $R^{(b)}(t)$, $t \geq 0$, in the time interval $\langle 0, \theta \rangle$, $\theta > 0$, at the state r_m has the normal distribution with the expected value

$$\hat{M}_m = E[\hat{\eta}_m] \cong p_m \theta, m = 1,2,\ldots,\varpi, \quad (74)$$

where p_m are given by (62).

7.3. Modelling losses of COVID-19 pandemic

We denote by

$$Q_m(t), t \geq 0, m = 1,2,\ldots,\varpi, \quad (75)$$

the COVID-19 pandemic losses associated with the process of human activity degradation $R(t)$, $t \geq 0$, at human activity degradation state r_m, $m = 1,2,\ldots,\varpi$, in the time interval $\langle 0, t \rangle$.
Thus, the approximate expected value of the total COVID-19 pandemic losses in the time interval $\langle 0, t \rangle$ associated with the process of human activity degradation $R(t)$, $t \geq 0$, can be defined by

$$Q(t) = \sum_{m=1}^{\varpi} p_m \cdot Q_m(t), \quad (76)$$

where p_m mean the limit transient probabilities of the unconditional process of human activity degradation at its particular states and defined by (73), and $Q_m(t)$, $t \geq 0$, are defined by (75).
The losses associated with the particular human activity degradation states are involved with negative consequences in the human living, economy and administration area. For instance, the types of consequences such as the closure of shops, closure of industrial works and flight cancelation can be considered as the negative ones. These losses can be expressed by the cost of the negative consequences.
Under the assumption, if we fix the number of kinds of human activity degradation consequences by ξ and the cost function of this consequence lasting t by

$[K_m(t)]^{(j)},$

for $j = 1,2,\ldots,\xi$, $m = 1,2,\ldots,\varpi$, than the loss is expressed by the total cost of all consequences lasting *t* and is given by

$Q_m(t) \cong \sum_{j=1}^{\xi} [K_m(t)]^{(j)},$

for $m = 1,2,\ldots,\varpi$.
Furthermore, according to (76), the total expected value of losses for the fixed time φ, $\varphi > 0$, associated with the process of human activity degradation can be evaluated by

$$Q(\varphi) = \sum_{m=1}^{\varpi} p_m \cdot \left[\sum_{j=1}^{\xi} [K_m(\varphi)]^{(j)}\right]. \quad (77)$$

8. Optimization of COVID-19 pandemic human safety

Considering the person health safety function $\boldsymbol{IS}(t,\cdot)$, $t \geq 0$, defined by (24)–(25) and related to the human living condition change process $L(t)$, $t \geq 0$, coordinate given by (26), it is natural to assume that this human living condition change process has a significant influence on the system safety. This influence is also clearly expressed in the equation (30) for the mean values of the person lifetimes in the person health safety state subsets. From the linear equation (30), we can see that the mean value of the person lifetime $\boldsymbol{I\mu}(u)$, $u = 1,2,\ldots,z$, in the person health safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, is determined by the limit values of transient probabilities c_l, $l = 1,2,\ldots,w$, of the human living condition change process at the person living condition states c_l, $l = 1,2,\ldots,w$, and the mean values $[\boldsymbol{I\mu}(u)]^{(l)}$, $u = 1,2,\ldots,z$ $l = 1,2,\ldots,w$, of the system conditional lifetimes in the safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, at these living condition states. Therefore, the system lifetime optimization approach based on the linear programming can be proposed (Klabjan, 2006). Namely, we may look for the corresponding optimal values $\dot{q}_l$, $b = 1,2,\ldots,w$, of the transient probabilities q_l, $l = 1,2,\ldots,w$, of the human living condition change process at the human living condition to maximize the mean value $\boldsymbol{I\mu}(u)$ of the system lifetime in the human health safety state subsets $\{u, u+1,\ldots,z\}$, $u = 1,2,\ldots,z$, under the assumption that the mean values $[\boldsymbol{I\mu}(u)]^{(b)}$, $b = 1,2,\ldots,v$, $u = 1,2,\ldots,z$, of the person living conditional lifetimes in the human living safety state subsets are fixed. As a special case of the above formulated person health lifetime optimization problem, if r, $r = 1,2,\ldots,z$, is a human health critical safety state, we want to find the optimal values $\dot{q}_l$, $l = 1,2,\ldots,w$, of the transient probabilities q_l, $l = 1,2,\ldots,w$, of the person human living condition process at the human living condition states to maximize the mean value $\boldsymbol{I\mu}(r)$ of the person lifetime in the human health safety state subset $\{r, r+1,\ldots,z\}$, $r = 1,2,\ldots,z$, under the assumption that the mean values $[\boldsymbol{I\mu}(r)]^{(l)}$, $l = 1,2,\ldots,w$, of the person conditional lifetimes in this human health safety state subset are fixed. More exactly, we formulate the optimization problem as a linear programming model with the objective function of the following form

$$\mathbf{I}\boldsymbol{\mu}(r) = \sum_{l=1}^{w} q_l [\boldsymbol{I\mu}(r)]^{(l)}, \qquad (78)$$

for a fixed $r \in \{1,2,\ldots,z\}$ and with the following bound constraints

$$\check{q}_l \le q_l \le \hat{q}_l, \ \sum_{l=1}^{w} q_l = 1, \qquad (79)$$

where

$$[\boldsymbol{I\mu}(r)]^{(l)}, [\boldsymbol{I\mu}(r)]^{(l)} \ge 0, \ l = 1,2,\ldots,w, \qquad (80)$$

are fixed mean values of the person conditional lifetimes in the human health safety state subset $\{r, r+1,\ldots,z\}$ and

$$\check{q}_l, \ 0 \le \check{q}_l \le 1 \text{ and } \hat{q}_l, \ 0 \le \hat{q}_l \le 1, \ \check{q}_l \le \hat{q}_l,$$

$$l = 1,2,\ldots,w, \qquad (81)$$

are lower and upper bounds of the unknown transient probabilities q_l, $l = 1,2,\ldots,w$, respectively.
Now, we can obtain the optimal solution of the formulated by (78)–(81) the linear programming problem, i.e. we can find the optimal values $\dot{q}_l$ of the transient probabilities q_l, $l = 1,2,\ldots,w$, that maximize the objective function given by (67). The maximizing procedure is described in (Kołowrocki & Magryta, 2020; Magryta-Mut, 2020).
Finally, after applying this procedure, we can get the maximum value of the person total mean lifetime in the human health safety state subset $\{r, r+1,\ldots,z\}$ defined by the linear form (78), in the following form

$$\mathbf{I}\dot{\boldsymbol{\mu}}(r) = \sum_{l=1}^{w} \dot{q}_l [\boldsymbol{I\mu}(r)]^{(l)} \qquad (82)$$

for a fixed $r \in \{1,2,\ldots,z\}$.
Further, by replacing the limit transient probabilities q_l, $l = 1,2,\ldots,w$, existing in the formulae (24)–(26) by their optimal values $\dot{q}_l$, $b = 1,2,\ldots,w$, we get the optimal form of the system safety and the expressions for all remaining safety indicators considered in Section 4.

9. Minimization and mitigation of COVID-19 pandemic consequences

From the linear equation (76), we can see that the mean value of expected COVID-19 pandemic losses $Q(t)$, $t \ge 0$, associated with the process of human activity degradation $R(t)$, $t \ge 0$, is determined by the limit value of transient probabilities p_m, $m = 1,2,\ldots,\varpi$, of the process $R(t)$ at its particular states r_m, $m = 1,2,\ldots,\varpi$, and the mean value of losses $Q_m(t)$ associated with the process $R(t)$ at the state r_m, $m = 1,2,\ldots,\varpi$.
Therefore, the optimization based on the linear programming (Klabjan & Adelman, 2006; Kołowrocki & Soszyńska-Budny, 2011/2015; Tang et al., 2007; Vercellis, 2009) of the COVID-19 pandemic losses associated with the process of the environment degradation $R(t)$, $t \ge 0$, can be proposed. Namely, we may look for the corresponding optimal values $\dot{p}_m$, $m = 1,2,\ldots,\varpi$, of the limit transient probabilities p_m, $m = 1,2,\ldots,\varpi$, of the process of human activity degradation $R(t)$, $t \ge 0$, at the state r_m, $m = 1,2,\ldots,\varpi$, to minimize the mean value of COVID-19 pandemic losses $Q(t)$, $t \ge 0$, (Klabjan & Adelman, 2006.).
Thus, we may formulate the optimization problem as a linear programming model with the objective function of the following form

$Q(t) = \sum_{m=1}^{\varpi} p_m \cdot Q_m(t), t \geq 0,$ (83)

with the following bound constraints

$\check{p}_m \leq p_m \leq \hat{p}_m, \sum_{m=1}^{\varpi} p_m = 1,$ (84)

where $Q_m(t), Q_m(t) \geq 0, m = 1,2,\ldots,\varpi$, are fixed mean values of the losses associated with the process of human activity degradation $R(t)$ at the state $r_m, m = 1,2,\ldots,\varpi$, for a fixed $t, t \geq 0$, and

$\check{p}_m, 0 \leq \check{p}_m \leq 1$ and $\hat{p}_m, 0 \leq \hat{p}_m \leq 1, \check{p}_m \leq \hat{p}_m,$

$m = 1,2,\ldots,\varpi,$ (85)

are lower and upper bounds of the unknown transient probabilities p_m, $m = 1,2,\ldots,\varpi$, respectively.

Now, we can obtain the optimal solution of the formulated by (83)–(84) the linear programming problem, i.e. we can find the optimal values $\dot{p}_m$, $m = 1,2,\ldots,\varpi$, of the limit transient probabilities p_m, $m = 1,2,\ldots,\varpi$, that minimize the objective functions given by (83). The minimizing procedure is described in (Bogalecka, 2020).

Finally, after applying this procedure, we can get the optimal value of the losses associated with the process of human activity degradation $R(t)$ defined by the linear form (83), giving its minimum value in the following form

$\dot{Q}(t) = \sum_{m=1}^{\varpi} \dot{p}_m \cdot Q_m(t),$ (86)

for a fixed $t, t \geq 0$.

The knowledge of optimal transient probabilities $\dot{p}_m$, $m = 1,2,\ldots,\varpi$, of the transient probabilities p_m, $m = 1,2,\ldots,\varpi$, at the particular states of the process of human activity degradation may be the basis to mitigate the COVID-19 pandemic consequences. These optimal values of limit transient probabilities at particular states of the process of human activity degradation minimize the mean value of COVID-19 pandemic losses. It can be the basis of some suggestions on new strategy assuring lower COVID-19 pandemic losses concerned with human activity degradation.

The suggestions on the way of minimizing the COVID-19 pandemic losses coming directly from the practice are the basis for creating the general procedures and strategies assuring the COVID-19 pandemic consequences decreasing the human and economy losses. In practice it includes the following proactive and reactive strategies, such as:

- applying the basic hygiene rules (regularly and thoroughly cleaning hands, avoiding touching eyes, nose and mouth),
- crowded spaces avoidance,
- staying with strangers in the shortest possible time,
- keeping the shopping in the shortest possible time or making shopping through the Internet,
- cleaning and disinfecting frequently touched surfaces,
- isolating sick persons,
- taking care of sick persons,
- staying home in the case of illness.

10. Kind of sufferer infected by COVID-19 pandemic identification

In a preliminary approach, according to the background given in Section 1, to illustrate our intentions, we arbitrarily assume that the person with COVID-19 can be identified/characterized by $o = 6$ parameters:

- age, assuming value v_1,
- BMI, assuming value v_2,
- gender, assuming value v_3,
- blood type, assuming value v_4,
- health condition, described by the number of undesirable health symptoms according to the list:
  - lung diseases (cancer, asthma, tuberculosis etc),
  - cancer (other than lung),
  - a person after surgery,
  - other chronic diseases (hypertension, heart disease, diabetes etc.),
  - a person permanently taking medicines,
  - assuming value v_5,
- education, assuming value v_6.

Futher, we fix for each parameter, the sets their values v_i, $i = 1,2,\ldots,6$, can belong to. Each set is divided into m_i, $i = 1,2,\ldots,6$, disjoint sets that are presented in Table 1.

Thus, the number of person kinds is

$$v = m_1 \cdot m_2 \cdot m_3 \cdot m_4 \cdot m_5 \cdot m_6$$

$$= 6 \cdot 3 \cdot 3 \cdot 4 \cdot 5 \cdot 5 = 5400$$

Table. 1. Parameters values and numbers of sets

Parameter v_i, $i = 1,2,\dots,6$	Paramter values set/subsets	Number of subsets m_i, $i = 1,2,\dots,6$
v_1	$\langle 0,120\rangle$: $\langle 0,10)$, $\langle 10,20)$, $\langle 20,30)$, $\langle 30,50)$, $\langle 50,70)$, $\langle 70,120\rangle$	$m_1 = 6$
v_2	$\langle 0,50\rangle$: $\langle 0,18)$, $\langle 18,25)$, $\langle 25,50\rangle$	$m_2 = 3$
v_3	$\{1, 2, 3\}$: $\{1\}$, $\{2\}$, $\{3\}$	$m_3 = 3$
v_4	$\{1, 2, 3, 4\}$: $\{1\}$, $\{2\}$, $\{3\}$, $\{4\}$	$m_4 = 4$
v_5	$\{1, 2, 3, 4, 5\}$: $\{1\}$, $\{2\}$, $\{3\}$, $\{4\}$, $\{5\}$	$m_5 = 5$
v_6	$\{1, 2, 3, 4, 5\}$: $\{1\}$, $\{2\}$, $\{3\}$, $\{4\}$, $\{5\}$	$m_6 = 5$

and they are as follows:

$$k_1: v_1 \in \langle 0,10), v_2 \in \langle 0,18), v_3 = \{1\}, v_4 = \{1\}, v_5 = \{1\}, v_6 = \{1\},$$

$$k_j: \begin{cases} v_1 \in S_{1,\mathrm{O}(j,1,[6,3,3,4,5,5],6)} \\ v_2 \in S_{1,\mathrm{O}(j,2,[6,3,3,4,5,5],6)} \\ v_3 = \{\mathrm{O}(j,3,[6,3,3,4,5,5],6)\} \\ v_4 = \{\mathrm{O}(j,4,[6,3,3,4,5,5],6)\} \\ v_5 = \{\mathrm{O}(j,5,[6,3,3,4,5,5],6)\} \\ v_6 = \{\mathrm{O}(j,6,[6,3,3,4,5,5],6)\} \end{cases}$$

where

$$[S_{1,j}]_{1\times 6} = [\langle 0,10), \langle 10,20), \langle 20,30), \langle 30,50), \langle 50,70), \langle 70,120\rangle],$$

$$[S_{2,j}]_{1\times 3} = [\langle 0,18), \langle 18,25), \langle 25,50\rangle],$$

and $\mathrm{O}(j,i,[6,3,3,4,5,5],6)$ for $i = 1,2,\dots,6$, is the value of the order function:

...

$$k_{5400}: v_1 \in \langle 70,120\rangle, v_2 \in \langle 25,50\rangle, v_3 = \{3\}, v_4 = \{4\}, v_5 = \{5\}, v_6 = \{5\}.$$

Further research in the above preliminary approach is intended to be done in the cooperation with the specialists involved directly in the COVID-19 pandemic practice.

11. Human living conditions of COVID-19 pandemic sufferer identification

According to the background given in Section 2, we assume that the human living condition change process states can be characterized by $a = 7$ parameters:

- population density (number of persons per km^2), assuming value w_1,
- residence building (one from the list below), assuming value w_2,
  - single family home
  - semi-detached house / row-house, multi-family home,
  - cooperative, townhouse, multi-family residential flat, skyscraper,
  - bedsit, dormitory, pied-à-terre, other, e.g. prison, retirement home, nursing home,
  - no permanent residence, hotel, workers' hotel,
- mean of transport (to be chosen from the list below), assuming value w_3,
  - walking and individual transport (car, moped, motorcycle, bicycle, scooter),
  - small group transport (shared access by proprietary means of transport), collective labor transport (passenger van, employee bus),
  - regional public transport (small bus, regional railways),
  - city and intercity public transport (bus, trolleybus, tram, metro, fast city rail, bus, train),
  - other transport (taxi, plane, ferry, cable car),
- workplace (number of persons met daily in the work area, monthly average), assuming value w_4,
- hygienic conditions (determined by the number of fulfilled points below), assuming value w_5:
  - access to running water (water, soap, toilet) and/or health services,
  - space conditions (keeping the distance),
  - use of disinfectants (hands, everyday objects, personal items in the workplace), disinfection of hygienic and sanitary rooms (cloakrooms, washrooms, dining rooms, showers, door handles, buttons),
  - air conditioning (higher probability of infection), ventilation (airing the room – lower probability of infection),

- lifestyle (determined by the number of fulfilled points below), assuming value w_6,
  - smoking, including electronic cigarettes (yes / no),
  - physical activity (yes/no),
  - diet (cooking, balanced diet, organic food / fast food, gluten or lactose intolerance, lack of good eating habits),
- mobility, assuming value w_7,
  - temporary migrations (e.g. economic, for tourist purposes),
  - permanent migrations,
  - no mobility.

Futher, we fix for each parameter, the sets their values w_i, $i = 1,2,\ldots,7$, can belong to. Each set is divided into n_i, $i = 1,2,\ldots,7$, disjoint sets that are presented in Table 2.

Thus, the number of human living condition change process states is

$$w = n_1 \cdot n_2 \cdot n_3 \cdot n_4 \cdot n_5 \cdot n_6 \cdot n_7$$

$$= 5 \cdot 5 \cdot 5 \cdot 4 \cdot 4 \cdot 3 \cdot 3 = 18000$$

and they are as follows:

$$c_1: v_1 \in \langle 0, 750), v_2 = \{1\}, v_3 = \{1\},$$

$$v_4 \in \langle 0, 5), v_5 = \{1\}, v_6 = \{1\}, v_7 = \{1\},$$

$$c_j: \begin{cases} v_1 \in S_{1,\mathrm{O}(j,1,[5,5,5,4,4,3,3],7)} \\ v_2 = \{\mathrm{O}(j,2,[5,5,5,4,4,3,3],7)\} \\ v_3 = \{\mathrm{O}(j,3,[5,5,5,4,4,3,3],7)\} \\ v_4 \in S_{4,\mathrm{O}(j,4,[5,5,5,4,4,3,3],7)} \\ v_5 = \{\mathrm{O}(j,5,[5,5,5,4,4,3,3],7)\} \\ v_6 = \{\mathrm{O}(j,6,[5,5,5,4,4,3,3],7)\} \\ v_7 = \{\mathrm{O}(j,7,[5,5,5,4,4,3,3],7)\}, \end{cases}$$

where

$$[S_{1,j}]_{1\times 5} = [\langle 0, 750), \langle 750, 1500),$$

$$\langle 1500, 2250), \langle 2250, 3000),$$

$$\langle 3000, 4000\rangle],$$

$$[S_{4,j}]_{1\times 4} = [\langle 0, 5), \langle 5, 10), \langle 10, 50), \langle 50, 100\rangle],$$

and $\mathrm{O}(j, i, [5,5,5,4,4,3,3], 7)$ for $i = 1,2,\ldots,7$, is the value of the order function:

Table. 2. Parameters values and numbers of sets

Parameter w_i, $i = 1,2,\ldots,7$	Paramter values set/subsets	Number of subsets n_i, $i = 1,2,\ldots,7$
w_1	$\langle 0, 4000\rangle$: $\langle 0, 750)$, $\langle 750, 1500)$, $\langle 1500, 2250)$, $\langle 2250, 3000)$, $\langle 3000, 4000\rangle$	n_1=5
w_2	$\{1, 2, 3, 4, 5\}$: $\{1\}$, $\{2\}$, $\{3\}$, $\{4\}$, $\{5\}$	n_2 = 5
w_3	$\{1, 2, 3, 4, 5\}$: $\{1\}$, $\{2\}$, $\{3\}$, $\{4\}$, $\{5\}$	n_3 = 5
w_4	$\langle 0, 100\rangle$: $\langle 0, 5)$, $\langle 5, 10)$, $\langle 10, 50)$, $\langle 50, 100\rangle$	n_4 = 4
w_5	$\{1, 2, 3, 4\}$: $\{1\}$, $\{2\}$, $\{3\}$, $\{4\}$	n_5= 4
w_6	$\{1, 2, 3\}$: $\{1\}$, $\{2\}$, $\{3\}$	n_6 = 3
w_7	$\{1, 2, 3\}$: $\{1\}$, $\{2\}$, $\{3\}$	n_7 = 3

$$c_{18000}: v_1 \in \langle 3000, 4000\rangle, v_2 = \{5\},$$

$$v_3 = \{5\}, v_4 \in \langle 50, 100\rangle, v_5 = \{4\},$$

$$v_6 = \{3\}, v_7 = \{3\}.$$

12. COVID-19 pandemic human safety identification

According to the background given in Section 3, to define the person health safety states, we preliminarily consider the following COVID-19 pandemic symptoms s_i, $i = 1,2,\ldots,11$:

s_1 – fever and/or chills,
s_2 – cough,
s_3 – fatigue,
s_4 – loss of taste and/or smell,
s_5 – shortness of breath and/or difficulty breathing,
s_6 – headache and/or sore throat and/or muscle and/or body aches,
s_7 – other (e.g. nausea or vomiting and/or diarrhea etc.),
s_8 – positive test for COVID-19,
s_9 – symptoms requiring hospitalization,
s_{10} – supplemental oxygen requirement,
s_{11} – death,

where $s_1, s_2, \ldots, s_7$ are the primary symptoms and $s_8, s_9, \ldots, s_{11}$ are the serious symptoms.

Based on these symptoms we fixed the number of health safety states (excluding health safety state 0) $z = 7$ and we distinguished the following seven $(z + 1)$ health safety states:

- a health safety state 7 – no COVID-19 pandemic symptoms are observed (the person is full safe),
- a health safety state 6 – from 1 to 3 COVID-19 pandemic primary symptoms are observed (the person is less safe and suspected of COVID-19),
- a health safety state 5 – more than 3 COVID-19 pandemic primary symptoms are observed (the person is possible sick with COVID-19),
- a health safety state 4 – positive test for COVID-19 and no COVID-19 pandemic symptoms are observed,
- a health safety state 3 – positive test for COVID-19 and at least one COVID-19 pandemic primary symptom is observed,
- a health safety state 2 – positive test for COVID-19 and hospitalization is required,
- a health safety state 1 – positive test for COVID-19 and hospitalization and supplemental oxygen are required,
- a health safety state 0 – death directly caused by COVID-19.

Further research in the above preliminary approach is intended to be done in the cooperation with the specialists involved directly in the COVID-19 pandemic practice. The cooperating experts are expected to be delivering the statistical data necessary to identyfication of COVID-19 pandemic human safety such as the numbers of persons being at the particular above mentoned health safety states and realizations of conditional lifetimes at these states.

13. COVID-19 pandemic human activity threats identification

According to the background given in Section 6.1, to define the states of human activity threats as the consequences of the COVID-19 pandemic human safety exceeding the critical health safety state, we preliminarily consider the following kinds of threats E^i, $i = 1,2$:

E^1 – a sufferer infected other person and caused its COVID-19 sickness,

E^2 – a sufferer infected other person and did not caused its COVID-19 sickness (a person can infect other person).

Further research in the above preliminary approach is intended to be done in the cooperation with the specialists involved directly in the COVID-19 pandemic practice. The cooperating experts are expected to be delivering the statistical data necessary to identyfication of COVID-19 pandemic human activity other threats.

14. COVID-19 pandemic human activity degradation identification

According to the background given in Section 6.2, to define the states of human activity degradation caused by the process of human activity threats by the COVID-19 and exceeding the critical health safety state, we distinguish the set of $\delta = 4$ kinds of parameters that define the human activity degradation

- operation of industrial plants, assuming value ϖ_1, expressed in percentages,
- operation of services, assuming value ϖ_2, expressed in percentages,
- operation of (COVID-19) hospitals, assuming value ϖ_3, expressed in percentages,
- operation of education, assuming value ϖ_4, expressed in percentages.

Futher, we fix for each parameter, the sets their values ϖ_i, $i = 1,2,\dots,4$, can belong to. Each set is divided into v_i, $i = 1,2,3$, disjoint sets that are presented in Table 3.

Table. 3. Parameters values and numbers of sets

Parameter ϖ_i, $i = 1,2,3,4$	Paramter values set/subsets	Number of subsets v_i, $i = 1,2,3$
ϖ_1	$\langle 0, 100\rangle$: $\langle 0, 30)$, $\langle 30, 70)$, $\langle 70, 100\rangle$	$v_1 = 3$
ϖ_2	$\langle 0, 100\rangle$: $\langle 0, 30)$, $\langle 30, 70)$, $\langle 70, 100\rangle$	$v_2 = 3$
ϖ_3	$\langle 0, 100\rangle$: $\langle 0, 30)$, $\langle 30, 70)$, $\langle 70, 100\rangle$	$v_3 = 3$
ϖ_4	$\langle 0, 100\rangle$: $\langle 0, 30)$, $\langle 30, 70)$, $\langle 70, 100\rangle$	$v_4 = 3$

Thus, the number of states of the process of human activity degradation is

$$\varpi = v_1 \cdot v_2 \cdot v_3 \cdot v_4 = 3 \cdot 3 \cdot 3 \cdot 3 = 81$$

and they can be numerated in the following preliminary way:

$$r_1\colon \varpi_1 \in \langle 0, 30), \varpi_2 \in \langle 0, 30), \varpi_3 \in \langle 0, 30), \varpi_4 \in \langle 0, 30),$$

$$r_j: \begin{cases} \varpi_1 \in S_{O(j,1,[3,3,3,3],4)} \\ \varpi_2 \in S_{O(j,2,[3,3,3,3],4)} \\ \varpi_3 \in S_{O(j,3,[3,3,3,3],4)} \\ \varpi_4 \in S_{O(j,4,[3,3,3,3],4)}, \end{cases}$$

where

$$[S_j]_{1\times 3} = [\langle 0, 30), \langle 30, 70), \langle 70, 100\rangle],$$

and $O(j, i, [3,3,3,3], 4)$ for $i = 1,2,3,4$, is the value of the order function:

...

r_{81}: $\varpi_1 \in \langle 70, 100\rangle, \varpi_2 \in \langle 70, 100\rangle,$

$\varpi_3 \in \langle 70, 100\rangle, \varpi_4 \in \langle 70, 100\rangle.$

Further research in the above preliminary approach is intended to be done in the cooperation with the specialists involved directly in the COVID-19 pandemic practice. The cooperating experts are expected to be delivering the statistical data necessary to identyfication of COVID-19 pandemic human activity degradation states.

15. Conclusion

The first approach to the comprehensive investigation of all problems concerned COVID-19 pandemic concerned with mathematical modelling, statistical identification, prediction and optimization of COVID-19 pandemic suffer health safety impacted by living conditions is presented. The next step will be focused on development of the proposed tool through the studying and including of ideas included in the WHO recent publications on the topic (World Health Organization Publications on COVID-19, 2021) and other publications (Bin et.al., 2020; Eid, 2020; Wölfel, 2020).

The authors' nearest ambitious is to contact the officials of WHO and to organise with their support a strong high scientific and practical quality International Consortium to prepare the research project proposal on the COVID-19 pandemic consequences minimization and mitigation and conduct it successfully for the goodness of the whole world.

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