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RESILIENCE ASSESSMENT IN CRISIS RESPONSE PHASE – TENTATIVE APPROACH

Abstract

The purpose of this paper is to indicate a possible measure of resilience of a local society. The concepts of resilience versus vulnerability are discussed. Two dimensions of resilience are considered: the first one, related to a security system organized by local authority and defined in the paper as systemic barriers and the second one, connected with a subjective possible reaction of population to a hazardous event defined as supplementary barriers. In the research of features of supplementary barriers their effectiveness was estimated in a questionnaire fulfilled by the crisis management staff in thirty regions in Poland. Employing the probability of success or failure, calculations of effectiveness of systemic and supplementary barriers were summarized giving the measure of strengthened or weakened entire safety system at the local level. A matrix of resilience was constructed.

Keywords: resilience, vulnerability, risk, systemic and supplementary safety barriers

OCENA ODPORNOŚCI W FAZIE REAGOWANIA NA KRYZYS – PODEJŚCIE WSTĘPNE

Abstrakt

Celem artykułu jest wskazanie możliwej miary odporności społeczeństwa lokalnego. Omówiono koncepcje odporności oraz podatności na zagrożenia. Rozważane są dwa wymiary odporności: pierwszy – związany z organizowanym przez władze lokalne systemem bezpieczeństwa i określany w pracy jako bariery systemowe oraz drugi – związany z subiektywną możliwą reakcją ludności na zdarzenie niebezpieczne, określany jako bariery dodatkowe. W badaniach cech barier dodatkowych ich skuteczność oceniono w kwestionariuszu wypełnionym przez sztaby zarządzania kryzysowego w trzydziestu regionach w Polsce. Stosując prawdopodobieństwo sukcesu lub porażki, podsumowano obliczenia skuteczności barier systemowych i uzupełniających, dając miarę wzmocnionego lub osłabionego całego systemu bezpieczeństwa na poziomie lokalnym. Skonstruowano macierz odporności.

Słowa kluczowe: odporność, podatność, ryzyko, systemowe i uzupełniające bariery bezpieczeństwa

1. Introduction

Permanent processes of changes of the surrounding natural and civilizational environment force individuals, community, organizations, states and even international institutions (at a global scale) to carry out continuous processes of adaptation to new conditions. Such processes of changes and of adaptation do not proceed smoothly. In many cases they take place rapidly and cause violent phenomena that affect everyday life and pose a threat to the citizens, their cultural and/or material values causing their losses and very often threatening their existence. As a result of the interaction of these phenomena crises situations often may emerge, which can acquire personal, local, regional or even global dimensions. Following Boin, one should understand that a crisis situation means that something bad is threatening a person, a group, an organization, a culture or a society, and that something should be done urgently and amidst uncertainty [4]. Crisis situations very often emerge regardless of our expectations. In this paper, a crisis situation should be understood as a situation where at least one out of following three cases take place: (a) necessity of assembling a crisis management team (CMT) to cope with the materialized threat, (b) need for strong cooperation of many services during the occurrence of an unwanted event and (c) absence of certain necessary equipment for special use when it is needed. In general, a crisis situation can be interpreted as the potential for loss of control of a spreading threat, leading to a crisis. The scale of a crisis situation is a function of the resilience of protected objects and systems and it even might assume a personal dimension. Resilience plays an important role in crisis management. The concept of resilience has its own complexity due to the joint influence of socio-technical and socio-cultural-economical intricacies [6, 1]. Human behaviour related to threats perception [25] influences the security system, i.e., affects resilience [18]. It is worth considering how the characteristics of the population living in the area at risk, their socio-cultural background and vulnerable values interact with the security system organised by the local authorities responsible for civil protection. There are some parameters that describe the organized security system and characterise its effectiveness. For instance, one of such parameters can be the time range from an alarm call to arrival on the scene. In Poland, according to relevant regulations that time it should equal to max. 15 min. Generally, it is assumed that during this period a rescue activity should be the most effective.

However, the misbehaviour of protected persons and their inappropriate attitude towards a negatively impacting event can strongly compromise this assumption. In such a case resilience becomes considerably weakened. The situation can also be converse. Although arriving of the first responder on the scene exceeds 15 minutes, proper and adequate reaction of people may "enhance" resilience, strengthening it. Phrases *weakening and strengthening resilience* mean constraining consequences of a threat, provided it occurs. The second section shortly characterizes the concept of resilience. The subsequent one presents a methodology that allows assessing resilience, taking into consideration the above discussed human factor.

2. Concept of resilience

Many authors determine resilience in different ways. For example, Kwok [12] describes resilience following Paton and Johnson [16] "…as the adaptive capacities of social system to bounce forward from natural hazard event. That is, disaster resilience refers to individuals' and groups' abilities to learn from, adapt to co-exist with natural hazards and their potential consequences…". John de Boer [8] has analyzed the concept of resilience as interconnected with the fragility concept in regard to the city indicating that these two concepts are not antonyms although they are not mutually exclusive. Both of them are strictly related to risk. According to the authors, resilient cities are those that are able to maintain and potentially enhance the delivery of their core functions before, during and after exposure to shocks and stresses. This definition distinguishes three phases of crisis management, and namely: (1)c prevention and preparedness (before exposure), response (during action the minimising of consequences) and recovery/rehabilitation (after exposure). In NIST [15] the authors have discussed resilience gaps and prioritizing efforts aimed at closing them after critical infrastructure disruption, that is only after disaster (recovery phase). They determine resilience gap as a difference between the desired time to recover damages and the anticipated time depending on the hazard level. However, a glossary elaborated by Aven [3] contains some definitions of resilience and examples of their metrics/descriptions. Following these authors, one should understand resilience as: the ability of a system to minimise the initial adverse effects (absorptive capability) of a disruptive event (stressor) and the time/speed and costs at which it is able to return to an appropriate functionality/equilibrium (adaptive and restorative capability). The measure of resilience is expressed by the probability that a system can sustain its functionality when faced by strong stress or (unexpected) disturbances. In this case two phases, response and recovery, are taken into account by the authors.

This article aims to assess resilience during the response phase. As an effect, in this paper resilience and its measures refer to the above mentioned definition provided by the glossary. However, the expression *the ability of a system* will be understood as the ability of the security system organized by an authority responsible for safety mutually interlinked with some characteristics of population subjected to destructive events. The ability of a security system organized by decision makers responsible for the security systemic barriers is defined. The probability of success is defined as the measure of effectiveness of systemic barriers. By definition, success means the degree of fulfilling a planned (desired effect of) action during the response phase. In other words, it means that the designed parameters of an activated system are reached. For example, in Poland one of the parameters of systemic barriers is the above mentioned arrival time, i.e., operational time of arrival on the scene after receiving an alarm call. However, statistics show that this parameter is fulfilled in 75% of calls. This suggests that the probability of success equals to 0.75 and of course, the probability of failure assumes the value of 0.25.

Independently of how systemic barriers are functioning there is another factor which should be taken into account to estimate the probability of success in a more precise way. This is the human factor [23] especially the vulnerability of people, which plays a significant role during disaster growth. Therefore, it seems reasonable to include this factor in resilience estimations.

There are many papers dedicated to this issue [13, 2, 8, 17]. For instance, Chipangura [5] explains the social constructivism and objectivism concept within the context of disaster risk. Briefly, when characterizing this paper the key problem appears to be that the social constructivism perspective of disaster risk is subjective. Authors describe implications of objectivism and constructivism in the risk of disaster. In this perspective, theoretical discussions and practical value acquire importance.

Tab. 1. Vulnerability indicators

HIGH	VULNERABILITY	LOW
High	Geographic isolation of the community from others	low
High	Extent to which community members are isolated from each other	low
Low	Degree of self sufficiency	high
Low	Level of community spirit (Social Capital)	high
High	Degree to which families are dispersed geographically	low
Low	Mobility of community members	high
Low	Equality of distribution of authority	high
High	Level of inherent conflict within community	low
Low	Risk awareness	high
High	Susceptibility to source of risk	low
Low	Resilience with respect to a realised source of risk	high
Low	Level of preparedness, both response and recovery	high

Source: [21]

Vulnerability may be described in different ways. A highly detailed research has been executed by Schneiderbauer [19]. The examples of vulnerability indicators are given by Sullivan [21] in Table 1. These indicators can be interpreted as an extent of the ability to cope with hazards. An item shown in the table, "resilience with respect to a realised source of risk" as an indicator of vulnerability directly links vulnerability with resilience. Both terms: resilience and vulnerability are measures of the same category, namely the extent of the impact of hazards on the objects of exposure. They are inversely proportional, and both have different meanings. This observation relating to the definitions of resilience, vulnerability and, additionally, susceptibility, has a broader meaning and creates not only theoretical problems but their practical implementation. Although susceptibility is not the object of our considerations, to make some order we have to introduce this characteristic of the population to this discussion. Consequently, by virtue of its definition susceptibility means a value of a difference between the extent of damages in case of risk source occurrence and the value of changes of its initial conditions.

Another vulnerability definition is given by Aven [3]. Namely, vulnerability should be understood as a conditional risk of the occurrence of a risk source/agent, or vulnerability suggests uncertainty as to the severity of consequences, given the occurrence of a risk source. On the one hand, vulnerability could be considered as a part of the risk measure. In this case, vulnerability a priori is anticipated in scenario analysis process in risk assessment procedure. Furthermore, "real" vulnerability posteriori is estimated by experts who include in the scenario an analysis of possible human behaviours during disaster, which could be interpreted as a part of resilience. In short, experts' assessment answers the question: "To what extent, bearing in mind characteristics of the population, can protected people boost or diminish the effectiveness of systemic barriers?" From this viewpoint this phenomenon is determined as *supplementary barrier*s.

In conclusion, resilience is related to the effectiveness of both kinds of barriers, i.e. systemic barriers and supplementary ones. Moreover, it can be seen that vulnerability comprises two elements, one of which is related to the uncertainty of potential consequences comprised by the "engineering" risk assessment. The second one that is related to vulnerability including also the human factor, given the occurrence of the source of risk, belongs to resilience.

The first element is employed in the prevention and preparedness phase (before a disaster may occur). The second one can be interpreted as "real" damages that strictly correspond to the effectiveness of both categories of barriers in coping with the disruptive event and takes place during response phase.

There are many indicators of resilience. Hence, the fundamental problem is to identify indicators of resilience as much as is reasonably possible (AMARP). The AMARP concept is aimed at avoiding multiplying indicators up to a quantity that if gathered together could be out of control or even be contradictory. In the report [11], the authors underline that "Resilience measurement therefore requires multiple method assessment approaches that capture perceptions, opinions, judgements and the nature of social interactions as well as the observable or easily measurable characteristics of social ecological systems…(…)…Measuring resilience means understanding the perspective of affected populations and individuals, so analysis must include context-specific, qualitative and subjective information – and some kind of measures of that information (…)".

Reactions of the population depend on many factors [20, 7, 14, 10, 22]. These reactions can strengthen or weaken the effectiveness of systemic barriers. On the one hand, some failures of systemic barriers sometimes can be "amended" by people because of their proper reactions. In such cases the systemic barriers may be strengthened. On the other hand, very effective rescue job performed by a crisis team or services can be "spoiled" by people who feel threatened and afraid. In these circumstances, human behaviour can be inadequate to the situation and they are able to significantly amplify consequences of an unwanted event in spite of the appropriate functioning of relevant services. It is obvious that this time systemic barriers are weakened. Since the measure of effectiveness of such barriers is expressed by the probability of success, the number of crisis situations should be considered as a random variable. A possibility of their occurrence may be expressed either quantitatively or qualitatively. However, there are rather rare statistical data related to hazards leading to crisis situations; usually the possibility of its occurrence is estimated by experts expressing the extent of their belief based on their experience, intuition or knowledge. In both cases the above mentioned crisis situation can occur.

3. Theoretical base of crisis situation, risk and resilience

To consider the link between the occurrence of a crisis situation and a resilience measure, it is necessary to outline first the security concept. There are many definitions of security. In this discussion, one should understand the term security as "a state of natural and/or civilizational spaces characterized by acceptable risk" [24] (safe: without unacceptable risk) [3]. The value of risk (regardless whether it is quantitative or qualitative) is a parameter fully characterizing security. It can be said that risk is a measure of security. Knowing the value of risk means knowing "everything" about security. Nevertheless, it is worth noticing that on the one hand risk is connected with future events that have not happened yet and contains uncertainties to potential consequences. On the other hand, in real disaster circumstances (response phase) people can react in different ways and this human factor in many cases is not taken into account in risk assessment process. Because of this even during routine action a crisis situation may emerge.

The degree of avoidance of a crisis situation that means the extent of the ability to adapt to dramatic changes taking place in the surroundings during unwanted event creates resilience in the response phase. Poorer resilience means more possibilities of a crisis situation arising.

A conclusion driven from the foregoing discussion is that risk, resilience (possibility of crisis situation) and both kinds of barriers (effectiveness of systemic and supplementary barriers) are linked and can be expressed by the following formula:

$$\text{Res.} = f(R, B_T), \tag{1}$$

where Res. – resilience, R – risk, B_T – resultant effectiveness of systemic and supplementary barriers. Resilience is a function of two independent variables: risk and resultant effectiveness of both kinds of barriers.

A calculation of summed effectiveness can be presented in the following form:

$$Pr^s = p_{sys.} + p_{sup.} - p_{sys.} \times p_{sup.} \tag{2}$$

where: Pr^s – probability of success; $p_{sys.}$ – effectiveness of systemic barriers; $p_{sup.}$ – effectiveness of supplementary barriers.

For example, let us characterise the effectiveness of systemic barriers by value $p_{sys.} = 0.75$. If people behave in an appropriate way, the number of victims may be sufficiently smaller than in the case when people are not prepared. Data show that preparedness of people as a "supplementary barrier" lowers the number of victims by ca. 10%, i.e. $p_{sup.} = 01$.

Then the effectiveness of the security system equals to:

$$Pr^s = 0.75 + 0.1 - 0.75 \times 0.1 = 0.78$$

This suggests that the system that takes into consideration the human factor is more reliable than if it results from effectiveness of systemic barriers only. As an effect, total barriers (B_T) are stronger than each of them separately.

Now, let us consider the same example but the inappropriate behaviour of protected people multiplies the number of victims by ca. 10%. In this case, supplementary barriers weaken the systemic barriers. The probability of failure of the security system in case of the potential failure of systemic barriers equals to $p_{sys}^{f} = 0.25$ or the probability of supplementary barriers failing, equals to $p_{sup.}^{f} = 0.1$ which can be calculated according to formula:

$$Pr^f = p_{sys.}^{f} + p_{sup.}^{f} - p_{sys.}^{f} \times p_{sup.}^{f} \tag{3}$$

where index *f* means failure. Substituting the numbers, we obtain $Pr^f = 0.33$. The result means that success probability of the security system equals to $Pr^s = 0.67$. Systemic barriers are weakened and as a result resilience is weakened. Hence, the possibility of crisis situation arises.

However, there are parameters characterizing systemic barriers that are very difficult to estimate, especially if we are speaking about interservice communication or even interoperability. The latter factor, due to its importance, plays an exceptional role during a crisis situation. Nowadays there is an intensive discussion about interoperability according to Dillon [9]: "...More recently, it (interoperability) entered the emergency services' lexicon and applies to the ability of responders to work together for a common purpose…". One of the solutions to such problems is the effectiveness of experts of both systemic and supplementary barriers in making estimations according to a methodology described in the following section.

4. Methodology of Research

Poland is divided into over three hundred local administrative areas (county analogue). They are diversified with respect to: their geographical characteristics, from offshore to mountain areas, extent of industrialization and hazards of course. According to the Polish law, local authorities are responsible for establishing the security system. To fulfil this, crisis units were set up within the structure of county authority offices on each administrative level.

These units are obliged to create plans within the framework of crisis management – prevention phase; to be prepared in case of a hazard – preparedness phase; to react when such a threat does occur – response phase; to recover losses – rehabilitation phase. In the planning process risk assessment should be conducted. Hence, the following was done: (1) in each county the risk description, either qualitative or quantitative, was worked out, (2) the effectiveness of systemic barriers was estimated.

The aim of the research was to estimate the effectiveness of supplementary barriers and then to assess and to visualize the resilience of the security system. Data were obtained by applying the questionnaire method. The questionnaires were sent to crisis management officers from thirty counties. The above mentioned questionnaire was divided into two parts: part A – contained issues related to the vulnerability of exposed people; part B – issues related to supplementary barriers.

Participants, crisis management unit employees or/and experts, indicated the vulnerability and barriers that exist on areas prone to hazards they are responsible for. The range of vulnerability has been limited between [-10.0] negative points. The scale of barriers embraced the range of [0.10] positive points. Such a scale instead of range [0.1] was selected to facilitate the completion of the questionnaire for participants. After summing up the items of vulnerability for each threat indicated in questionnaire (for an individual county), the obtained results were divided by the number of elements in each category, i.e. for A by 10 (last column in Table 3) to get average values characterizing vulnerability separately for the specified two categories of losses. The same procedure was employed to barriers, i.e. the sum of points assigned to the elements for each threat (for individual county) was divided by 8 for B elements. Then, these average points related to vulnerability and barriers were summarized and divided by 10 to obtain outcomes within the range of [0.1] or [-1.0]. The last step is acceptable due to the general question "to what extent people can "overcome" the given threat" and can be interpreted as the probability although it is only roughly estimated.

In other words, these outcomes are interpreted as an extent of experts' beliefs that systemic barriers are either strengthened – positive range or weakened – negative range. As has been said, there are two possibilities of the results. They can be either negative or positive. A negative result testifies that vulnerability "overcomes" the barriers. This result means that on the given area and for the given threat the systemic barriers are weakened (equation 3). Conversely, if the result is positive the barriers "overcome" vulnerability and systemic barriers are strengthened (equation 2).

Each county selected the most dangerous hazard which occurred actually on its area. The questionnaire was completed accordingly to this hazard.

In Table 2, the identified hazards for each county are enumerated.

Tab. 2. Identified hazards for each county

County number	Hazard	County number	Hazard
1	Industrial accident	20	Forest fires
2,3	Hurricane	21	Dwelling fires
4	Building collapse	22	Transport of danger goods
5,6	Road accidents	23	Drought
7	Air transport accident	24	Blizzard
8	Freeze	25	Ammonia release
9	Unexploded bomb	26	Methanol release
10	Insects	27	Railway accident
11,	Arson	28	Chemical threat
12,13,14,15, 16,17,18	Flood	29	Radiological threat
19	Store fire	30	Mass accident

Source: own study

Vulnerability for the People category was investigated according to the following elements:

Part A – elements of vulnerability

1. Average population density of residents. *(-10 – for example highrise building; 0 – no people).*

Tab. 3. Vulnerability for the People category

County number/ Threat	**Number of A's element**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average vulnerability for the given threat (Sum divided by 10)**
1/ Industrial accident	-3	-7	-1	-3	-3	0	0	-5	-10	-5	**-3.7**
2/ Hurricane	-5	-10	-7	-4	-5	-2	-8	-7	-3	-8	**-5.9**
3/ Hurricane	-5	-5	-5	-7	-4	-5	-5	-3	-6	-6	**-5.1**
4/ Building collapse	-5	-5	-7	0	-2	0	0	-2	-7	-3	**-3.1**
5/ Road accidents	-3	-2	-3	0	-1	0	-1	-4	-2	-2	**-1.8**
6/ Road accidents	-7	-8	-6	-2	-1	0	0	-3	0	-9	**-3.6**
7/ Air transport accident	-3	-3	0	-4	-5	-5	-5	-5	-5	-5	**-4**
8/ Freeze	-5	-3	0	-2	-6	-4	-9	-1	0	-8	**-3.8**
9/ Unexploded bomb	-10	-10	-5	-10	-5	-10	-10	-10	0	-10	**-8**
10/ Insects	-4	-5	-7	-2	-7	-4	-5	-10	-6	-5	**-5.5**
11/ Arson	-4	-4	-3	-1	-1	-1	-1	-1	-3	-4	**-2.3**
12/ Flood	-4	-6	-6	-3	-5	-5	-4	-7	-6	-9	**-5.5**
13/ Flood	-7	-7	-5	-10	-6	-5	-5	-3	-7	-10	**-6.5**
14/ Flood	-1	-2	-1	-1	-3	-3	-2	-4	-1	-10	**-2.8**
15/ Flood	-5	0	0	-8	-6	-4	-4	0	-3	-10	**-4**
16/ Flood	-5	-5	0	-10	-6	-5	-6	-10	-10	-7	**-6.4**
17/ Flood	-4	-4	-6	-1	-3	-4	-1	-2	-6	-10	**-4.1**
18/ Flood	-3	-4	0	-1	-7	-10	-1	-3	0	-10	**-3.9**
19/ Store fire	-5	-5	0	-2	0	0	-1	0	-7	0	**-2**
20/ Forest fire	-1	-5	-8	-1	-6	-1	-1	-2	-6	-9	**-4**

County number/ Threat	Number of A's element										
	1	2	3	4	5	6	7	8	9	10	Average vulnerability for the given threat (Sum divided by 10)
21/ Dwelling fires	-5	-4	0	-8	-5	0	-2	-3	0	-5	**-3.2**
22/ Transport of dangerous goods	0	-1	0	-2	-2	-1	-2	0	-10	-3	**-2.1**
23/ Drought	-6	-5	-6	-7	-4	-2	-3	-3	-7	-8	**-5.1**
24/ Blizzard	-10	-8	0	-10	-4	-8	-8	-5	-4	-6	**-6.3**
25/ Ammonia release	-5	-6	0	-1	-2	0	-3	-3	-3	-4	**-2.7**
26/ Methanol release	-2	-1	0	0	-5	0	-1	0	-4	-10	**-2.3**
27/ Railway accident	0	0	-5	0	0	-5	0	0	-3	-5	**-1.8**
28/ Chemical threat	-5	-3	0	-4	-3	-3	-4	-2	-2	-6	**-3.2**
29/ Radiological threat	-3	-2	0	-1	-5	-4	-2	-5	-8	-10	**-4**
30/ Mass accident	-5	-4	-3	-4	-4	-2	-5	-3	-5	-3	**-3.8**
Average vulnerability for the given item of A's element for all threats (Sum divided by 30)	**-4.33**	**-4.47**	**-2.80**	**-3.63**	**-3.87**	**-3.10**	**-3.30**	**-3.53**	**-4.47**	**-6.67**	**-4.02**

Source: own study

2. Number of people temporary staying on the area *(-10 – mass event; 0 – nobody, negligible amount).*
3. Possibility of seasonal population increase *(-10 – a shedload of seasonal employees; 0 – no seasonal employees).*
4. Localisation of hospitals, institutions schools, nursery schools, nurseries on the prone area *(-10 – objects exposed to threats; 0 – no such objects).*
5. Level of physical fitness (including children, the elderly, people with disabilities, homeless people) *(-10 – most of people belong to one of these groups; 0 – young generation).*
6. Localisation of sports facilities *(-10 – facilities that can contain several thousand people; 0 – no such objects).*
7. Localization of commercial facilities *(-10 – mall or another big aerial facilities; 0 – no such objects).*
8. Other mass temporary events *(-10 – big markets; 0 – no such events)*

9. Localisation of industrial facilities *(- 10 – increased and big risk plants; 0 – no such objects).*
10. Localisation of a river or another kind of a water body *(- 10 – river or reservoir flood possible; 0 – no such objects).*

There were ten elements of vulnerability identified for the People category. They contain population characteristics, items 1, 2, 3, 5 and 8; threatened objects, items 4, 6 and 7; threats sources, items 9 and 10. In Figure 1, the results of estimated vulnerability for each county for selected by them threats are illustrated.

Below, the bar chart presents the estimated vulnerability. On the top line there is a number assigned to a county. Element values of vulnerability for each county averaged per A's are set on the vertical axis.

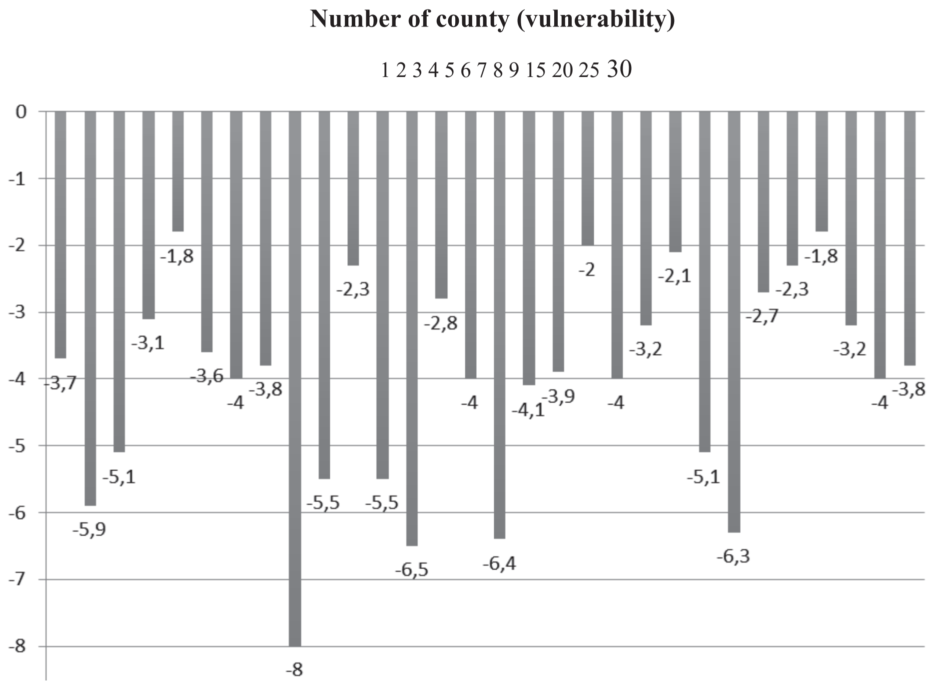

Fig. 1. Elements values of vulnerability averaged per A's

Source: own study

The numbers on top line indicate the number of counties. In the same manner strength of barriers were assessed.

The next step of the research was to estimate the features of county which strengthen the systemic barriers. In this case, supplementary barriers were characterized by eight elements as follows:

Part B – elements of barriers

1. Natural and artificial shelter (for instance, during flood, radiation, explosion, toxic cloud, fragmentation) (*0 – no such shelters; 10 – there are shelters with a 100% effectiveness*).
2. Societal threats awareness *(0 – entire lack knowledge of threats; 10 – familiarized threats due to their frequent occurrence).*
3. Social linkage (*0 – lack of strong neighbour relations among residents, lack of common traditions, inability to cooperate; 10 – long lasting traditions, very strong relations).*
4. Preservability (*0 – lack of knowledge and skills to proper self-protective reaction; 10 – proper knowledge and skills to self-protection).*
5. Characteristics of the population (*0 – more elder residents; 10 – more younger residents*).
6. Access to services (*0 – no services on administrative area; 10 – very easy and quick access of well – prepared services).*
7. Possibility to warn the major part of the population *(0 – no possibility of warning at all*; *10 – possibility to warn over 90% of population).*
8. Possibility of maintaining the necessary goods and services to survive *(0 – lack of means allowing to deliver such goods and services; 10 – there is such a possibility).*

The results of estimations are summarized in Table 4 and Figure 2.

Tab. 4. Barriers for the People category

County number/Threat	**Number of B's element**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Average Barriers for given threat**
1) industrial accident	5	5	3	5	5	6	3	5	**4.625**
2) Hurricane 1	4	7	1	5	5	7	5	2	**4.5**
3) Hurricane 2	7	5	6	7	8	9	7	9	**7.25**
4) Building collapse	2	5	4	6	7	5	2	1	**4**
5) Road accident 1	5	10	5	5	8	10	10	10	**7.875**
6) Road accident 2	2	9	7	7	5	8	6	9	**6.625**
7) Air transport accident	5	5	6	6	7	8	7	5	**6.125**
8)Freeze	1	5	4	6	7	3	8	5	**4.875**
9) Unexploded bomb	5	2	5	5	7	10	10	10	**6.75**
10) Insects	0	3	5	3	8	6	8	7	**5**

County number/Threat	Number of B's element								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Average Barriers for given threat**
11) Arson	0	0	1	1	1	6	2	1	**1.5**
12) Flood 1	5	3	8	6	2	8	8	7	**5.875**
13) Flood 2	5	9	8	7	5	8	10	9	**7.625**
14) Flood 3	3	4	7	7	6	8	10	7	**6.5**
15) Flood 4	10	8	6	7	6	7	10	10	**8**
16) Flood 5	6	7	6	7	3	6	7	5	**5.875**
17) Flood 6	5	7	5	7	5	8	7	6	**6.25**
18) Flood 7	3	8	5	7	4	7	8	8	**6.25**
19) Store fire	0	0	3	3	5	7	5	2	**3.125**
20) Forest fires	1	5	5	5	5	3	7	7	**4.75**
21) Flat fires	4	8	3	4	5	6	5	1	**4.5**
22) Transport of dangerous goods	1	4	3	5	5	7	10	8	**5.375**
23) Drought	2	3	3	4	6	5	6	4	**4.125**
24) Blizzard	8	10	8	9	7	9	10	7	**8.5**
25) Ammonia release	0	1	4	3	7	5	5	8	**4.125**
26) Methanol release	0	2	8	7	5	10	7	10	**6.125**
27) Railway accident	5	7	5	7	5	4	8	5	**5.75**
28) Chemical threat	3	4	3	5	5	9	7	5	**5.125**
29)Radiological threat	4	6	1	3	5	5	8	1	**4.125**
30) Mass accident	0	2	4	3	6	5	4	3	**3.375**
Average of Barriers for given item of all threats (Sum divided by 30)	**3.37**	**5.13**	**4.73**	**5.40**	**5.50**	**6.83**	**7.00**	**5.90**	**5.48**

Source: own study

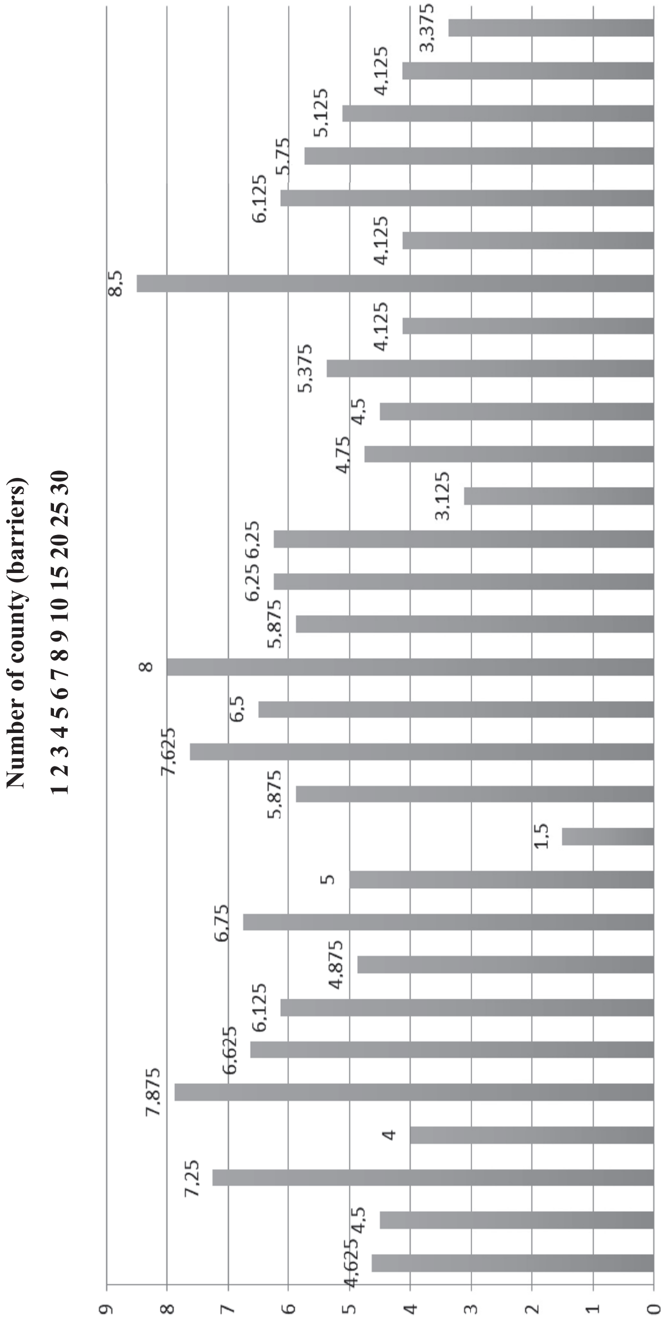

Fig. 2. People category – county average barriers
Source: own study

To check out whether systemic barriers are strengthened or weakened vulnerability and barriers need to be summarised for each county. To rescale the result and to get the range of [0,±1], all sums are divided by 10. In Table 5 and Table 6 results of summing are gathered. The second line denoted if supplementary barriers (SB) are negative or positive.

Tab. 6. Sum of vulnerability and SB (part 2)

	Number of counties														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
SB x 10^{-1}	0.09	-0.14	0.25	0.09	0.61	0.3	0.21	0.11	-0.13	-0.05	0.08	0.04	0.12	0.37	0.4
Pr_i^s	0,77	**0.67**	0.81	0.77	0.90	0.82	0.80	0.76	**0.65**	**0.71**	0.77	0.76	0.78	0.84	0.85

Source: own study

Table 5. Sum of vulnerability and SB (part1)

	Number of counties														
	16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
SB x 10^{-1}	0.05	0.21	0.24	0.11	0.08	0.13	0.33	-0.1	0.22	0.38	0.46	0.46	0.19	0.01	-0.04
Pr_i^s	0.76	0.80	0.82	0.78	0.77	0.78	0.83	**0.68**	0.80	0.85	0.87	0.87	0.80	0.75	**0.72**

Source: own study

From these both tables it can be seen that in five cases supplementary barriers weaken systemic ones. This applies for the county:

- No 2 where a hurricane was identified as the most risky hazard, the probability of systemic barriers is lowered by a factor that equals to 0.14,
- No 9 where an unexploded bomb was identified as the most risky hazard, the probability of systemic barriers is lowered by a factor that equals to 0.13,
- No 10 where insects were identified as the most risky hazard, the probability of systemic barriers is lowered by a factor that equals to 0.05,
- No 23 where drought was identified as the most risky hazard, the probability of systemic barriers is lowered by factor that equals to 0.10,
- No 30 a mass accident was identified as the most risky hazard, probability of systemic barriers is lowered by factor which equals to 0.04.

In the remaining cases SB strengthen the systemic ones.

Probabilities Calculation

Let us assume in all considered examples that the probability of success of systemic barriers equals to 0.75 (example is taken from Polish systemic barrier where in 75% cases the first rescue vehicle arrives on time on the scene) so the failure of systemic barriers equals to 0.25. In this case, the value of probability success or failure of SB equals to 0.

To calculate the probability of strengthened barriers use is made of the equation (2).

For instance, county No 1:

$$Pr_1^s = 0.75 + 0.09 - 0.75 \times 0.09 = 0.77$$

Because SB strengthened the systemic barriers, the probability of success of the security system increases from 0.75 up to 0.77. In the same way, a calculation should be made for the remaining counties where systemic barriers are strengthened.

Employing the equation (3) it is possible to calculate the probability failure of the entire security system that is the case when failure systemic barriers or failure SB are considered.

Since in county No 2 SB weakens the systemic barriers one should calculate probability of failure of safety employing the equation (3).

For county No 2:

$$Pr_2^f = 0.25 + 0.14 - 0.25 \times 0.14 = 0.33$$

it means that probability of success equals to:

$$Pr_2^s = 1 - 0.33 = 0.67$$

instead of 0.75 if SB has not been taken into account.

In the same manner the probability of failure of the remaining counties where systemic barriers are weakened should be calculated. In the Table 5 and Table 6 in the third line the probabilities of success of the security systems are indicated.

5. Discussion

The results analysis shows that maximum value of probabilities of success of the security system equals to 90% for county No 5. It means that the population is on the highest level of preparation to cope with road accidents as compared to other threats. These kinds of events are met in everyday life. The smallest level of preparation of the population belongs to county No 9 where a hazard related to an unexploded bomb was recorded. Such accidents are very rare in Poland. Another conclusion that may be drawn is that SB can play a sufficient role on this area where there is a chronic hazard of flood (county No 14 and 15). Another group where systemic barriers are highly amplified is represented by counties (No 25 and No 26) with numerous enterprises and with a high awareness of hazards. County No

27 can be included in this group as well. However, a mass railway accident is very rare event; the result indicated in Table 6 (87%) means that a mass accident (took place not long ago in Poland and it was the only one during the last more than fifty years) activated many inhabitants to take actions before the first responders arrived on scene. This activity turned out to be highly effective.

Having at disposal the effectiveness of the security system and the estimated risk related to the given threat it is possible to work out a resilience matrix. Before constructing the resilience matrix a risk assessment for the given threat in each county should be executed. Let us assume that in county No 5 the security system has an effectiveness of 90% and risk is assessed as high. It is possible to determine the coordinates of resilience on the resilience matrix.

1.0				**County No 5**	
0.8			**County No 15**		
0.6		**County No 10**		**County No 9**	
0.4					
0.2					
Eff./Risk →	**Negligible**	**Small**	**Medium**	**High**	**Very high**

Very strong resilience
Strong resilience
Medium resilience
Weak resilience

Fig. 3. Resilience matrix for different counties

Source: own study

In Figure 3 an example of resilience matrix is shown. The estimated risk is strictly related to the given county and specific hazard. In that way, resilience of different counties can be compared in regard to their own most risky threat. In practice, what is a medium risk for one county can turn out a high risk for another, however they can have the same resilience.

The presented methodology allows constructing a resilience matrix for one common threat for all counties. The first step is a risk assessment for this threat to be carried out for all counties, and the second one is an assessment of the security system effectiveness likewise in the described method. Moreover, there a resilience matrix may be established for one country but with different threats and associated risks.

6. Conclusions

The presented approach is an attempt at presenting the method of possibility of assessing community resilience in the response phase. This approach is based on a logical chain that links safety, vulnerability, sensitivity, and finally also resilience including crisis situation concepts. A special questionnaire to estimate the effectiveness of systemic and supplementary barriers has been devised. Due to the lack of statistical data characterizing certain elements of the barriers, estimation was carried out based on the experts' beliefs. Consequently this method is of a semi-quantitative character. The result of the assessment can be illustrated in a matrix shape – resilience matrix. However, the entire approach comprises certain fundamental uncertainties that need to be expressed in a more precise way. First of all, a specification of elements of systemic and supplementary barriers that is incomplete and insufficiently precise gives rise to a big amount and variety of elements to be chosen. One has to consider a way of selecting both kinds of barriers to establish the fundamental (canonic) elements, which should be examined in each case. This allows the possibility of measuring resilience in the same way. The presented approach as outlined in this research is operable provided that the participants are aware that they estimate the degree of effectiveness understood as a probability of the security system succeeding during a disaster. A discussion is needed whether a chain adduced and defined in such a way, and namely: safety – vulnerability – sensitivity- resilience and crisis situation, constitutes the complete aspect of issues taken up in this paper.

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