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## THE USE OF PRELIMINARY HAZARD ANALYSIS TO ASSESS THE RISK OF DAMAGE TO THE TELECOMMUNICATIONS WIRED ACCESS NETWORK

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### ZASTOSOWANIE METODY PHA DO OCENY RYZYKA USZKODZEŃ SIECI NA PRZYKŁADZIE MIEDZIANEJ DOSTĘPOWEJ SIECI TELEKOMUNIKACYJNEJ

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#### Abstract

This article presents the results of studies relating to the possibility of the practical use of the preliminary hazard analysis method to assess the risk of damage to the telecommunications copper access network. Use of the PHA method allows the identification and evaluation of risk factors; it enables the comparison of the risk of damage to components of the telecommunications copper access network located in different geographical areas. This generates the possibility of the effective application of a comparative analysis (including the service quality) by the operator for different network areas. The method also allows the setting of benchmarks for improving the effectiveness of the technical services of the operator.

**Keywords:** overhead and cable lines, copper access network, telecommunications wired access network, preliminary hazard analysis (PHA), damage risk assessment, risk management.

#### Streszczenie

W artykule przedstawiono wyniki badań własnych dotyczących możliwości praktycznego wykorzystania metody Preliminary Hazard Analysis (PHA) do oceny ryzyka wystąpienia uszkodzeń miedzianej dostępowej sieci telekomunikacyjnej. Zastosowanie metody PHA pozwala na identyfikację i ocenę czynników ryzyka. Umożliwia porównywanie ryzyka uszkodzeń komponentów miedzianej dostępowej sieci telekomunikacyjnej zlokalizowanej na różnych obszarach geograficznych. Generuje to możliwość skutecznego stosowania analizy porównawczej (m.in. jakości obsługi) przez operatora dla różnych obszarów sieci. Pozwala także na benchmarking w zakresie poprawy efektywności m.in. pracy służb technicznych operatora.

**Słowa kluczowe:** Preliminary Hazard Analysis, (PHA), miedziana dostępowa sieć telekomunikacyjna, ocena ryzyka uszkodzeń, zarządzanie ryzykiem.

## 1. Introduction

In the 21<sup>st</sup> century, effective electricity supply systems and efficient IT systems are strategic areas of activity undertaken to guarantee the proper functioning of states, societies and economies based on knowledge. This is an important issue in the following areas:

- ▶ in crisis management, where the key roles of electricity supply systems, communication systems and IT networks within the critical infrastructure are emphasised [41 – art. 3] – special attention is paid to making sure that such attributes of critical infrastructure remain available;
- ▶ in the context of ensuring broadly understood security [44] and effectiveness [13] at the micro-, meso- and macroeconomic level (in connection with the implementation of the Europe 2020 strategy for smart and balanced development [11]);
- ▶ in connection with the necessity of undertaking technical activities aimed at diagnosis and forecasting adverse events (damage) within a specific ICT network (particularly the identification and assessment of risk related to this damage in the context of the effective preparation of specialist engineering teams for technical performance of activities as part of interdisciplinary risk management.

The aim of this paper is to assess the options for use of the preliminary hazard analysis (PHA) method in order to evaluate the risk of damage to the telecommunications copper access network operating in the area of a selected district. In consideration of the above, the following objectives were attempted:

- ▶ defining the important terms related to the subject of this analysis,
- ▶ identifying and shortlisting the risk factors,
- ▶ using PHA for the assessment of the risk of damage to components of the telecommunications copper access network.

A description of the research methods used to accomplish the objectives of this study is provided later in this paper.

## 2. The risk of damage to the telecommunications copper access network – terminological issues

Definitions related to risk differ from each other as their range (broad or narrow) refers to different contexts, approaches and meanings [30]. These have been created to satisfy the requirements of various groups of interested parties (risk is defined differently by engineers [34], management specialists [31], lawyers, doctors [27] and physicians). Thus, depending on whether the author of the given definition creates it within the framework of a specific scientific discipline or for the needs of specific practical issues, not only is it possible to define risk differently, it is also possible to measure it differently [38]. However, emphasis is placed on the fact that ‘risk’ is an interdisciplinary term [23]. The common feature of the definitions proposed in the literature is that risk refers to many different things [8]. It is the type of the hazard (e.g.

for the management board, employees, investors, natural environment), the likelihood of an adverse event and the 'severity' of its effects, etc. which are of importance here [21].

Analysis of scientific publications allows the drawing of the conclusion that the issue of risk refers to the broadly understood security and technical aspects [2]. The authors emphasise that an unambiguous definition of risk is a very complex process as, depending on the given situation, the risk may well be in the form of damage, a hazard, or an adverse event [36]. It must be emphasised – although some authors overlook this – that risk is also the impact of uncertainty on a given objective [28 – section 3.48]. The impact may generate a negative or positive deviation from expectations (in the latter case, it generates chances) [12].

In technical sciences, it is particularly important to differentiate between risk and reliability. In practice, these terms are misused [32]. Reliability means the property that the system is able to fulfil its functions under specific conditions of existence and operation and during an assumed period of time [16]. In the context of this paper, the measure of network reliability is failure rate.

We encounter the risk when it is possible to indicate the actual hazard and estimate the likelihood of its occurrence. In situations characterised by uncertainty, it is not possible to unambiguously indicate the existing hazard and/or estimate its likelihood [33]. Uncertainty is the state of a lack or partial lack of understanding or knowledge of an event, its consequences or likelihood [29 – section 3.48].

Telecommunications law defines the telecommunications network as transmission systems and switching or routing devices as well as other resources including inactive network components, which enable the broadcasting, reception and transmission of signals by means of wires, radio and optical waves or other means that use electromagnetic energy irrespective of their type [40]. For the purposes of this 'paper' the main focus is on the access network and subscriber network built using copper cable technology.

An access network (within the meaning of the factory standard ZN-02/TD S.A.- 05 Construction of Copper Access Networks) is a network that covers a set of access lines in a given area [9] from the main distribution frame to the access point.

In contrast to an access network, a subscriber network is comprised of a network from the access point to a port at the customer's premises. Analysis of the report of the Office of Electronic Communications from the year 2016 allows the drawing of the conclusion that copper routes account for 95% of wired access networks (Fig. 2). Thus, it is important to identify the risk of damage to services based on the copper transmission medium.

A wired access network can be built using underground and/or overhead cables. The choice of the technology depends on many factors analysed at the design stage of the network. The network analysed in this paper uses xDSL (digital subscriber line) and LAN-Ethernet (ethernet-based local area network) technologies for the provision of services ordered by customers.

A hazard is an event which has an adverse effect on the proper functioning of the telecommunications service. In the context of this study, hazards may relate to deliberate or accidental events which disrupt transmission. Accidental events include weather anomalies, equipment and/or system failures, and natural disasters [3]. Thus, a hazard is the potential

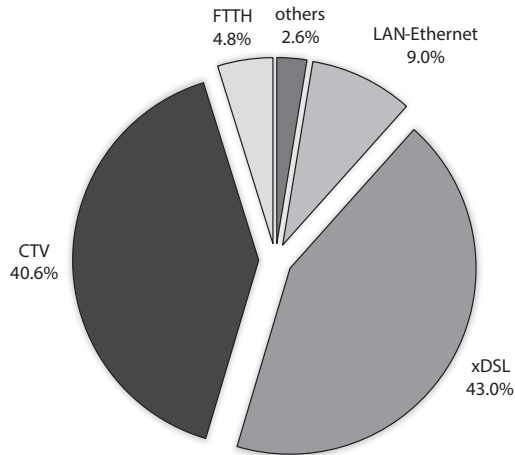


Fig. 1. Structure of the subscribers according to the used wired access technology  
 Note: The FTTH category uses fibre-optic cables and not copper cables. The 'other' category cannot be classified precisely. Cable television, xDSL and LAN-Ethernet use copper lines.  
 (Source: Compiled on the basis of data gathered by the Office of Electronic Communications for the year 2015 [35])

cause of an incident, which may result<sup>1</sup> in damage to the system/service recipient. In this paper, the risk of damage to the telecommunications network is considered from the point of view of an operator.

In this context of this study, damage is understood as interruption to or interference of the operation of the telecommunications service, which is reported by the customer to the relevant operator.

Risk of damage to the telecommunications network is considered unacceptable in instances where either or both of the following situations apply: there is a substantial likelihood of damage to the continuity and effectiveness of the services; the costs of restoring the required level of service following such damage are likely to be at a level that results in repair being deemed to be unprofitable by the operator.

### 3. Assessments of the risk of damage to a telecommunications wired access network using preliminary hazard analysis

In connection with the necessity to accomplish the objective of this study and also because of the subject of this study, a decision was taken to perform an overview of the available literature on the subject and to present the gist of the PHA (Preliminary Hazard Analysis) method.

<sup>1</sup> An effect is the result of an adverse event.

A case study was applied in the course of the research work. During the first quarter of 2016, as part of the scientific research, the author participated in field operations of a representative of one of the local telecommunications operators within the district<sup>2</sup> located in the area of the podkarpackie province and obtained empirical data. The researcher had access to important information included in the technical documentation of the network<sup>3</sup>. Additionally, detailed interviews were conducted with specialists who performed work on the copper network and with their managers.

A model of the analysed telecommunications network<sup>4</sup> is presented in Fig. 2.

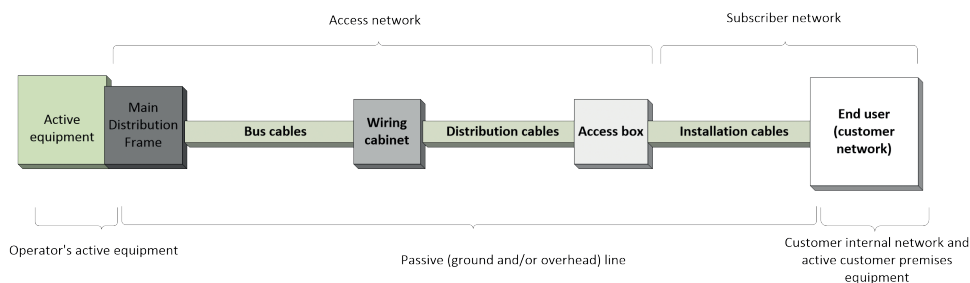


Fig. 2. Model of the analysed telecommunications network  
(Source: Own study)

Broadly speaking, it can be assumed that the analysed telecommunications network consists of active devices operated by the operator, underground and overhead passive lines and customers' internal networks including the active devices that are in their possession.

During the conducted analysis, the reliability of the analysed network was established at a level of 97%. This means that 3% of customers reported an issue regarding the faults that interfered with the proper functioning of the provided services during the analysed quarter.

The conducted studies allowed for the performance of typologisation based on the location of disruption in the provision of telecommunication services. The locations of the faults reported by customers which were identified during the 3-month period, referred to:

- ▶ active devices owned by the operator
- ▶ the telecommunications line for connecting operator's devices to the customer's port? (overhead lines were dominant)

<sup>2</sup> Disclosure of more detailed characteristics of the area covered by the analysis was not allowed.

<sup>3</sup> Because of security issues relating to users and the necessity to protect the competitive advantage of the company, no consent was given for the detailed publication of data, which would enable the identification of the operator and the analysed network.

<sup>4</sup> In the analysed case, the access network covers active equipment of the operator and the local loop (the circuit that connects the network termination with the access point to the fixed-line public telephone network, in particular, the main distribution frame).

- ▶ the customer's own network (defined as the line section starting from the customer's port, including active devices)
- ▶ the 'other' category, which covers events in which no damage was found and/or intervention was not justified, etc.

The presented typologisation became the basis for the identification of risk factors.

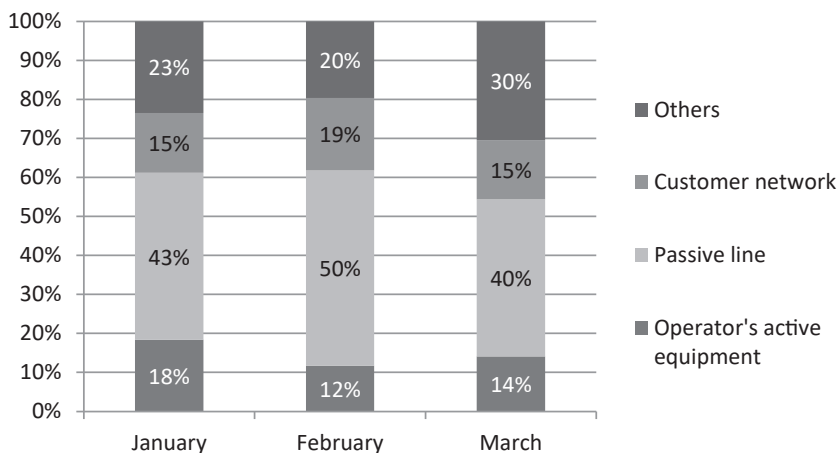


Fig. 3. Typologisation of faults which occurred during the period from January to March 2016 in the analysed geographical area (expressed in percentages)  
*N* = 292 (covers all the interventions of employees of the analysed telecommunications network operator) (Source: Own work based on the studies)

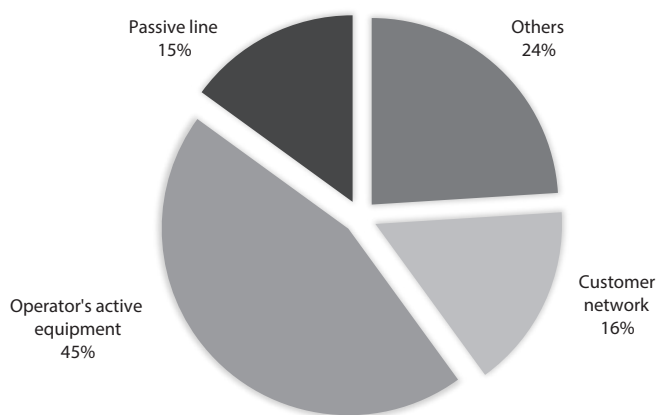


Fig. 4. Division of faults in terms of the location of adverse events (average values for the 3-month period, expressed in percentages); *N* = 292 (covers all the interventions of employees of the telecommunications network operator in the analysed geographical area)  
 (Source: Compiled on the basis of results of own studies)

Analysis of the data presented in Chart 2 allows drawing the conclusion that the percentage distribution of faults in the analysed area was similar in each month of the first quarter of 2016. Therefore, based on the data obtained during the study, the results were averaged in order to standardise the data and estimate the likelihood of damage in the given network element (Fig. 4).

It can be seen in Fig. 4<sup>1</sup> that 45% of faults were found in the passive line. During the analysed period, damage to the operator's equipment accounted for barely 15% of the analysed cases. The causes of 16% of the irregularities related to service functioning issues diagnosed in the internal network and/or devices owned by customers. The remaining 24% of cases mainly covered so-called alleged faults, in which issues reported to the operator by the customers were not confirmed by service technicians (e.g. the customer had managed to fix the issue before the arrival of the technical services).

In this paper, the author uses the term 'repair time required'; this refers to important cost-generating factors [10]. It represents the use of work time measured by the number of man-hours spent on the completion of activities/interventions on network components and provides a parameter for the allocation of resource costs to activities in the activity based costing<sup>5</sup> [19]. In accordance with the TDABC (time-driven activity-based costing) concept<sup>6</sup> [17], the time-driven use of resources allows the cost pools involved in the performance of activities to be easily allocated, especially in the case of the service companies with a high share of human resources<sup>7</sup> [37], [39]. Because of the editing limitations and the objectives set for this paper, analysis of costs was not a subject of this study.

An additional element of our studies included attempts to determine the average time required to repair damaged network elements. Based on analyses of documentation, the results of measurements and information obtained during in-depth interviews conducted with service technicians and managers, it was possible to average the time required to carry out an intervention. The data presented in Table 1 refers to the period from the moment of dispatching a service technician to determine the cause and solve the reported issue to the moment of reporting effect of the intervention upon completion.

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<sup>5</sup> The literature on the subject indicates the use of the concept of the resource cost driver in economic practice. This driver is described as the time-driven use of the resource which allows for the allocation of the costs of difficult resources to activity based costing, using information about the working times of the respective employees. Activity-based costing (as one of the calculation methods) enables the best possible allocation of the overall costs incurred during a given period of time to the given elements responsible for the occurrence of these costs. In the case of the ABC method, costs are assigned to activities and cost objects (e.g. materials).

<sup>6</sup> Time-driven activity-based costing.

<sup>7</sup> In the case of the TDABC approach, the calculation of the costs of each service/repair requires: 1) the calculation of the costs of all resources allocated to the given type of activity; 2) the division of all the costs by the number of work hours of employees to obtain the cost per unit of available time; 3) the multiplication of the cost of the time unit by the number of units related to each cost object.

Table 1. Average time required to repair the telecommunications copper access network depending on the location of the fault within the analysed geographical area in the first quarter of 2016

Location of damage	Operator's equipment	Line	Customer's equipment and or network	Other
Required repair time	1 hour	2 hour	1.3 hour	0.5 hour

(Source: Compiled on the basis of results of own studies)

While analysing the time required to identify and/or repair an instance of damage, it is necessary to take into account the fact that it was determined from the point of view of specialist crews responding to requests made by customers. In the case of the defectiveness of customer's equipment and/or the network, the time required for damage repair was out of the operator's control. Pursuant to the agreement, the operator is not held liable for the customer network and/or equipment failures which interfere with the proper functioning of the service. The operator, when precluding the necessity of his intervention, may identify the problematic area to be on the side of the customer's network (e.g. related to the necessity to replace equipment). In such cases, the intervention time (limited to the identification of the cause of a fault on the subscriber's side) was specified to be an average of 1.3 h.

As a result of the abovementioned data, it is possible to proceed with the assessment of the risk of adverse events (faults) in the analysed telecommunications copper access network. Risk assessment is important as it allows the proper treatment of the risk, which can cover; the risk avoidance, the risk reduction, the risk transfer or the risk acceptance [29]. The risk handling involves a risk modification process by, among others, removal of the source of risk, change in consequences, the risk sharing and the risk retention [16– def. 3.8.1].

In literature regarding the issue of risk, authors indicate various methods for its assessment. The majority of the described methods are based on a similar operating scheme which is essentially the ranking in seriousness of adverse events, the determination of the likelihood of a given risk type and the estimation of the potential adverse effects/losses related to its occurrence again, [4, 15].

In order to achieve the objectives of this paper, a decision was taken to use the matrix method, which is referred to as preliminary hazard analysis (PHA). The PHA method is a universal method, which is characterised by a broad spectrum of options for its use in different areas<sup>8</sup> [45, 43, 46]. It is classified among the induction, qualitative, two-parameter, four-phase methods. Its use is recommended in the developmental phase of work (studies), design (modification) and construction (building). It is applied in the estimation of risk related to hazardous events which occur with regard to devices, machines and their systems [14, 24].

The use of this method requires making preliminary arrangements<sup>9</sup> [5]. Specifically, these activities include:

<sup>8</sup> The literature indicates that it is often used to assess industrial risk at a given workplace.

<sup>9</sup> The determination of the aim and scope, the selection of the team, the collection of information, etc.



- a) The identification of the risk – this includes the ongoing process of search, recognition and description of the risk (what may happen, where and why) [16 - def. 3.5.1, 25].
- b) The assignment of the likelihood<sup>10</sup> of an event (P) occurring to a given network element. For the purposes of this paper, a five-stage division of the likelihood has been adopted. During the creation of the abovementioned divisions, reference has been made to the results obtained during our own studies (Chart 3). Variant ‘1’ refers to a highly unlikely occurrence of an event/fault. The likelihood of occurrence ranges between 0% and 20% in this case. Variant ‘5’ refers to the occurrence of a very likely event/fault (from 81% to 100%).
- c) The assignment of a rating which refers to the time spent on interventions by the operator’s repair services to a given network element, which result in the fault being identified and, if possible, proper service being restored. A scale between 1 and 5 was adopted, where 1 refers to an intervention time up to 30 min, and 5 is an intervention time exceeding 2 hours.
- d) The determination of the risk level using the matrix (Fig. 5)

In accordance with ISO Guide 73, a risk includes both the combination of the likelihood of an event and its effects. In order to calculate the risk level based on the PHA method, the required formula is modified as follows:

$$R = S * P \quad \text{(formula 1)}$$

where:

R – the risk level

S – the degree which refers to the time required for the intervention of the operator’s services,

P – the likelihood of a fault of a given network element.

		Likelihood of a fault in reference to a given network element [P]				
		1 0–20%	2 21–40%	3 41–60%	4 61–80%	5 81–100%
Degree referring to the time required for the intervention of the operator’s repair services [S]	1 0–30 min.	1	2	3	4	5
	2 31–60 min.	2	4	6	8	10
	3 61–90 min.	3	6	9	12	15
	4 91–120 min.	4	8	12	16	20
	5 >120 min.	5	10	15	20	25

Fig. 5. Risk level determination matrix

<sup>10</sup> Likelihood must be understood as the degree of certainty that a given incident will happen.

Compiled on the basis of the guidelines of the Polish standard - PN-N-18002:2011 [26]).

The quantitative risk analysis consisted of the determination of the likelihood of a fault on a given network element and an indication of the consequences of such an adverse event taking place. The adverse effects were expressed in degrees from 1 to 5. The degrees refer to the time required by the operator's repair services to intervene (Table 1).

		Likelihood of a fault on a given network element [P]				
		1 0–20%	2 21–40%	3 41–60%	4 61–80%	5 81–100%
Degree which refers to the time required for the intervention of the operator's repair services [S]	Level					
	1 0–30 min	1	2	3	4	5
	2 31–60 min	<b>2 Operator's equipment</b>	4	6	8	10
	3 61–90 min.	<b>3 Customer's equipment and/or network</b>	6	9	12	15
	4 91–120 min.	4	8	<b>12 Line</b>	16	20
	5 >120 min.	5	10	15	20	25

Fig. 6. Specific levels of the risk of damage according to the respective locations.

If the calculated risk level ranges between 1 and 2, the risk is minimal – it is tolerated at the current level and no specific action is required

If the calculated risk level ranges between 3 and 9, the risk is average and must be managed [16 – def. 2.1, 22]. The area must be monitored in order to guarantee supervision of the costs and of whether the hazard moves to a different risk level range over time. The implementation of new solutions or improvements is justified if they do not result in any additional costs.

If the calculated risk level ranges between 10 and 25, the risk for the operator is high and significant. Despite the fact that it is within the tolerance limits, it may escalate to reach the intolerance limit<sup>11</sup> [47]. Because this is a risk, which requires particular attention, specific and comprehensive actions must be taken both in the short-term and in the long-term. In order to reduce the risk, it is necessary to strive for a reduction in the levels of some risk factors. The likelihood of a fault may be decreased by, for example, a change in the used technology or as a result of improvement in the process of identification of the cause of faults, which will significantly reduce repair times.

<sup>11</sup> The higher the risk level, the more attention is required. Tolerance with regards to risk does not mean acceptance of the given status quo and requires a response.

Analysis of the data presented in Fig. 6 allows the drawing of the conclusion that the most sensitive part of the analysed network was the passive line. Repairs of damage to components of this line required a comprehensive technical diagnosis; this included several specialist measurements, which often required service engineers to relocate and work at height as a result of the nature of the passive line. Such activities extended the time of restoration of the service; the average intervention time of the operator during completion of a repair order was estimated to be in the range of 1.5 to 2 hours and thus generated significant costs. It must be emphasised that the likelihood of damage in the area of the abovementioned network was very high. In order to ensure the usefulness and reliability of the network, which translates to a reduction in the likelihood of damage, it is necessary to apply the technologies and tools that allow for the shortening of the repair time. The diagnosis and improvement of the quality parameters of the copper network existing in a given area is absolutely vital as the highest risk of damage was actually observed in relation to the functioning of the network. In the context of technological changes, the rapid, gradual replacement of the copper access network with the fibre-optic network may turn out to be necessary [1, 6].

As a result of the conducted assessment of the risk of damage to the telecommunications copper access network, it was found that the second important reason for a lack of availability of the services was the customer's equipment and/or network; faults in this area accounted for 16% of the diagnosed causes of interventions carried out by the operator's employees. In order to minimise the risk of damage perceived by the service recipient, the customers may be offered professional installation of the internal network and lease of the customer premises equipment (CPE). If the services are unavailable, the entire responsibility for the restoration of the operation of the system lies with the operator, including the replacement of the equipment; this applies throughout the term of the agreement. This will undoubtedly shorten the time required to eliminate faults in the customer's network, contributing to a faster return of a properly functioning service.

#### **4. Conclusions/Summary**

The PHA method is a relatively cheap tool, which can be used to assess the risk of damage to the components of a telecommunications copper access network. It can be recommended as a useful diagnostic solution. Preliminary hazard analysis constitutes a useful tool from the point of view of both its technical and investment purposes. The use of the PHA method allows the identification and assessment of risk factors; it enables comparison of the risk of damage to the components of the telecommunications copper access network located in different geographical areas. This generates the possibility of using comparative analysis, i.e. benchmarking for the different network areas handled by the operator, or for the network performance. From a technical point of view, the location of the site where the number of faults is the largest is of key importance for the optimisation of technological solutions. The use of the PHA method in the analysed case allowed drawing the conclusion that the majority of faults in the telecommunications network were detected in the area of the passive line. This

is a very important finding for further considerations regarding the factors which determine the reliability of the ground and overhead passive line in a given geographical area during different seasons of the year. It is important to be aware that telecommunications networks are characterised by the variability of technical standards; this means that the replacement of their components is not essentially a consequence of wear and tear but rather their age. The gradual replacement of the permanent access networks is necessary; these networks are built mainly of cables with pairs of copper wires designed for analogue voice services with a frequency band of 3.4 kHz, at a length of the subscriber connection up to about 10 km. For the HDTV services, it is necessary to introduce subscriber access with the bit rate of around 50 Mbit/s and the construction of a new generation network (NGN) [7].

Pursuant to the recommendations of the European Commission described in the Digital Agenda for Europe [12], comprehensive and multi-dimensional measures must be undertaken so as to make sure that all Europeans will have a common and fast access to the Internet at competitive prices. Telecommunication network planning and maintenance involves complex issues that are in constant demand for better solutions [1]. By the year 2020, the European Union intends to guarantee access to lines with a capacity exceeding 30 Mbps. Additionally, the aim is to also provide at least half of the European households with access to connections with a capacity exceeding 100 Mbps [18]. While analysing the degree of accomplishment of the objectives mentioned above, it is clear that there is still a lot that needs to be done. In the year 2016, the capacity of 61% of lines was above 10 Mbps and almost 11% of users of these lines had access to the network with a capacity exceeding 100 Mbps [35].

On 20 September 2010, the European Commission adopted a recommendation on regulated access to next generation access networks (NGA). NGA was defined as wired access networks which consist of fibre-optic cables, either entirely or partially. Currently, copper networks are becoming more and more expensive to maintain; this is partly due to the cost of electrical power. Furthermore, the required capacities (above 30 Mbps), as a consequence of the parameters of copper cables, are available only at small distances (up to 1.5 km) from the telephone exchange [42]. Pursuant to article 16, section 4 of Directive 2002/21/EC, the national regulatory bodies are obliged to prepare regulations for the transition of copper networks to fibre-optic networks [48]. The Office of Electronic Communications (the national regulator) imposes an obligation on operators with significant market power (SMP) to provide access to fibre loops for alternative operators.

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