Effect of population density and network availability on deployment of broadband PPDR mobile network service

Matti Peltola and Heikki Hämmäinen

Matti Peltola is Consultant at the Department of Communications and Networking, Aalto University, Espoo, Finland.
Heikki Hämmäinen is Professor at the Department of Communications and Networking, Aalto University, Espoo, Finland.

Abstract

Purpose – *The purpose of the paper is to define the best deployment alternatives for a public protection and disaster relief (PPDR) mobile network service – the implementation alternatives being either a dedicated network, a commercial network or a hybrid of the two network types. The selection criteria are based on the social benefits that the PPDR mobile service is expected to bring to society. The critical parameters are population density and service availability, which both directly relate to the socioeconomic benefits achieved by providing broadband (BB) mobile services in various demographic areas.*

Design/methodology/approach – *A causal loop model has been developed to define the socioeconomic benefits of the PPDR network, the parameters being population density, service availability, socioeconomic value of the service and the costs of the network. The network solution alternatives are studied using the Finnish PPDR network as a reference – analysing various areas of the country with differing population densities from remote, rural and more densely populated suburban and urban areas.*

Findings – *Socioeconomic value is a common measure for assessing the value of governmental investments; population density has a strong impact on the optimum deployment alternatives as the socioeconomic value is directly proportional to this variable. The flat nationwide fee of the mobile users means that the users are subsidised in sparsely populated areas – and overcharged in densely populated areas. This is the main reason why the commercial network seems to be most feasible in rural areas, whereas the dedicated network works best in urban areas. Based on the case study, the commercial network is most preferable up to the point when the population density reaches 50-125 persons/km^2. After that point, the dedicated network becomes more appropriate. Proposals are being made to improve the availability of the commercial networks enabling them to serve as a PPDR network: ensuring priority functionality and a protected power supply; allowing PPDR subscribers the exclusive use of one of the 700 MHz spectrum bands in restricted, critical areas; and extending use of the existing narrowband PPDR network in areas where communication availability is crucial.*

Originality/value – *On the one hand, the financing of BB PPDR mobile networks is an unresolved issue in many countries. On the other hand, the ability of commercial BB networks to provide better quality of service is improving, making viable the alternative to subscribe for radio service from a commercial operator. Therefore, the feasibility study on how to provide an optimum mobile BB service for PPDR organisations is of real value at this time.*

Keywords *Broadband networks, Social benefits, PPDR, Public safety networks*

Paper type *Research paper*

1. Introduction

Public protection and disaster relief (PPDR) radio communication networks refer to those mission critical networks which are built for the voice and data communication of critical organisations like police and rescue – but are also of value for other organisations that provide society infrastructure services, such as railways and power utilities. The current dedicated PPDR networks offer secure and reliable mobile services for their users. The

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broadband (BB) mobile services make it possible to improve the operations of the users to create additional socioeconomic benefits, both in terms of cost saving and improved citizen safety, compared to earlier times, relying much on voice and short messaging services.

Traditionally the PPDR mobile networks have all been dedicated government-owned networks. Today, in Europe, PPDR networks are based mainly on the narrowband (NB) TETRA or TETRAPOL technologies (Peltola, 2013). Moreover, PPDR organisations also utilise commercial BB networks, although the availability of commercial networks in times of crisis cannot be taken for granted (Lezaack, 2017). The required BB mobile network capacity for PPDR users is somewhere between 500 and 4,000 kbit/s (Borgonjen, 2012), whereas the existing NB mission critical networks are only able to offer data speeds of 5-200 kbit/s (Peltola, 2013).

If commercial networks are utilised for the deployment of mobile BB for PPDR users, both the financing and radio spectrum issues will be more easily resolved. The commercial networks fulfil functionality (3GPP, 2013), security (end-to-end encryption), resilience requirements (multiple alternative networks) and communication performance issues (high bitrates and wide coverage), but the question has been raised whether commercial networks can fulfil the availability requirements of the authorities (Swan and Taylor, 2003; TCCA, 2012; Peltola and Kekolahti, 2015). The priority functionality has been developed for LTE technology (3GPP, 2016) to enable prioritised communication for certain user groups – if needed and allowed by regulators and operators. The congestion of traffic in LTE networks can be eliminated by taking into use the proposed quality of service (QoS) mechanisms (Airbus, 2017b), such as the subscriber specific parameters access class barring, allocation and retention priority and quality of service class identifier (3GPP, 2016); a multimedia priority service mechanism can be used to ensure the flow of the command messages from top down. A proper understanding of the availability of PPDR networks is necessary – irrespective of the platform, whether dedicated or a commercial network – and also which network type with specific services is able to generate the highest socioeconomic value.

The valuation of societal services – and the making of investment decisions based on those valuations – is a common practice used by the road construction administration (Finnish Transport Agency, 2011) when evaluating the profitability of new road construction projects. The same principles can be utilised for the purpose of evaluating new telecommunication investments. In many countries, studies have been completed to understand the optimum utilisation of spectrum and the costs and benefits of the implementation alternatives of PPDR mobile BB services – examples of such studies are several (Saijonmaa, 2009; Hallahan and Peha, 2011; Grous, 2013; SCF, 2015; Ure, 2013; Gierszal *et al.*, 2014; Peltola and Pesonen, 2014; Vinkvist *et al.*, 2014; Minehane *et al.*, 2014; Peltola and Hämmäinen, 2015; Australian Government, 2015; Delgado, 2015).

2. Research question

The purpose of the study is to define how to measure the effect of network availability together with population density on the deployment of a BB PPDR mobile service, the network alternatives being either a *dedicated* or *commercial* mobile network. The "commercial" network in this study refers to a network which can be utilised by both *commercial* and PPDR users; the "dedicated" network refers to a network with a frequency band in the specific area which is reserved solely for the utilisation of emergency agencies or other organisations that provide crucial services for society. The term "dedicated" takes no stance on either ownership or operational responsibility. The paper is done with the anticipation that the LTE technology will be used as BB technology as indicated in many studies (Nokia, 2012; Ferrus *et al.*, 2013; FCC, 2012).

The research question is as follows:

RQ1. What is the effect of network availability and population density on the deployment of a PPDR mobile network service?

The alternative deployment options are either a commercial, a dedicated mobile BB network or a combination of the two network types. The study focuses on the mobile access part of the mobile network solution.

The research question also covers issues such as how much potential socioeconomic value is created, based on new applications supported by the BB PPDR mobile network services; and in the particular area under review, what is the *Threshold* value of that population density between the optimal solutions? The study assumes that the PPDR network service utilises the 700 MHz band (Liikenne- ja viestintaministerio, 2016).

3. Modelling deployment of public protection and disaster relief mobile services

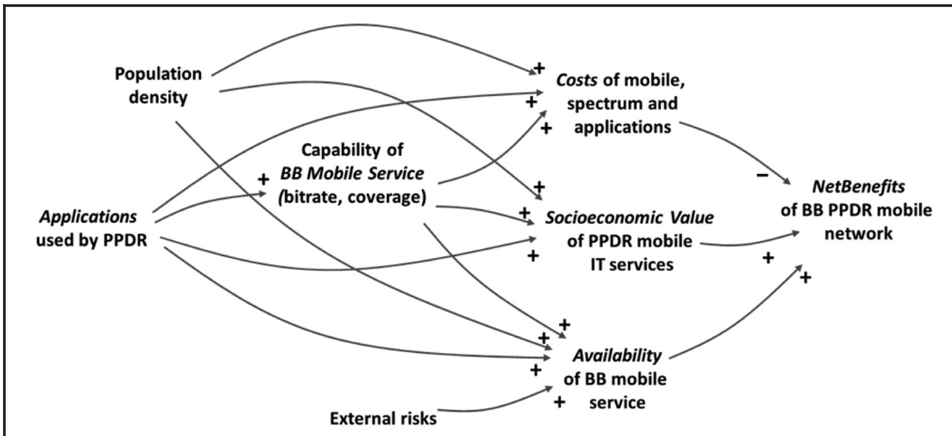
The causal loop analysis model (Figure 1) for the BB PPDR mobile network valuation is used to define the net socioeconomic value (later *NetBenefits*) of the PPDR mobile service. The *NetBenefits* comprises population density, availability, costs and the service capability of the network. The model shows the causalities, how the services of the PPDR agencies (police, rescue, etc.) are linked with the benefits to society and how PPDR mobile services are dependent on the mobile network services and the specific applications utilising the mobile PPDR network.

The new BB PPDR mobile BB service, the *BB mobile service* with *Applications*, creates a socioeconomic value for society, called *socioeconomic value*. To supply the *applications* with the help of the *BB mobile service* requires some investments and operations costs – later referred to as *Costs*.

The *availability* of the *BB mobile service* is defined such that the system is said to be unavailable (= *unavailability*) if any affected area is out of service or the service is seriously degraded. The *availability* can be threatened by not only the technical incompleteness but also some external risks, e.g. heavy traffic or cyberattacks. In the *dedicated* network case, the affected area has to consist of at least tens of NB PPDR base stations (Suomen Erillisverkot, 2014), and in the *commercial* network case, the affected area must consist of at least thousands of mobile users (Viestintavirasto, 2016).

The *NetBenefits* is the *socioeconomic value* multiplied by *availability* and subtracted by *costs* of the *BB mobile service* and *applications*, i.e.:

Figure 1 The causal loop model of broadband PPDR network valuation



Source: According to Sterman (2000)

$$NetBenefits = Availability \ x \ Socioeconomic \ Value(\rho) - Costs(\rho) \quad (1)$$

where ρ = *population density*

The *threshold* point is the equal value of the population densities in the two deployment alternatives, which yields equal *NetBenefits.*

4. Population density and availability

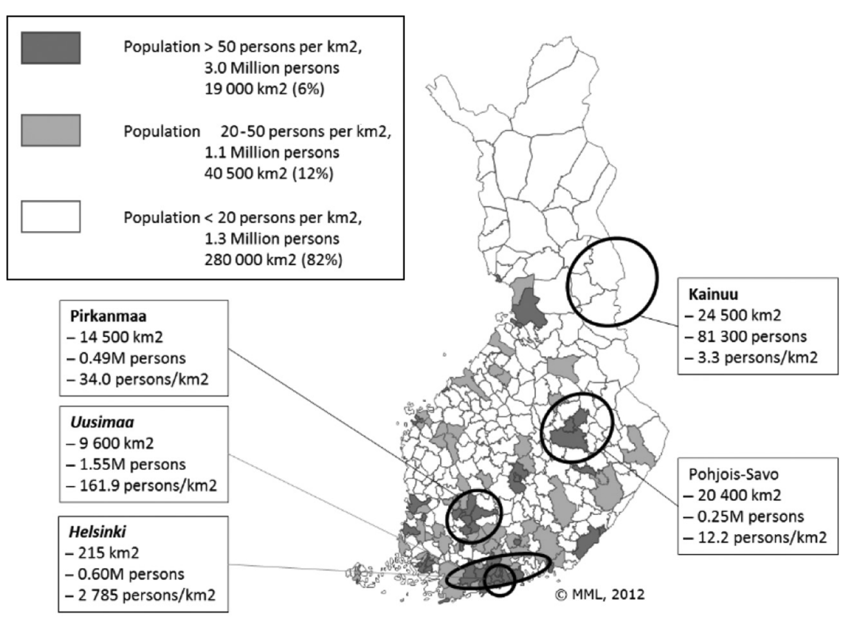
Population density is one of the key parameters when defining the *socioeconomic value* in a specific area. The number of incidents – when the *BB mobile services* are utilised and some value created for society – is closely correlated to the population density. Also, the cost of the network is directly related to the population density in the area under study, e.g. the number of buildings has an effect on the number of base stations.

In our analysis, *NetBenefits* is defined for five Finnish regions which have different population densities (Figure 2). The triggers for the *unavailability* of the network service can be divided into three classes:

1. a problem in a network element, which causes a local service interruption;
2. a trigger which causes a wide area service break in a network; and
3. a trigger which could cause a service break in all networks in the same area [e.g. a common power supply break, high communication peaks caused by emergency situations or an attack by hackers (DW, 2016)].

Class 1 problems are typically resolved by the coverage of the neighbouring base stations or the duplication of key network elements. Class 2 issues can be resolved by using alternative parallel networks to protect the service. Class 3 problems, however, are difficult to resolve from a *commercial* network perspective, because the larger number of base stations in *commercial* networks means that the power supply protection is expensive and high communication peaks during emergency situations or mass events seem to congest

Figure 2 Case network regions in Finland, population density in Finland



Source: Suomen Kuntaliitto (2013)

all *commercial* networks (Lezaack, 2017; Swan and Taylor, 2003) – even if some additional capacity is reserved beforehand.

4.1 Targets and statistics of network availabilities

Network availability depends on network technical capability, on the used applications within the network and on the number of users, which may overload the network. But many other issues can also influence the availability, such as cyberattacks, unreliable ownership, unsecured physical location, poor network coverage, unreliable or incapable personnel (Peltola and Kekolahti, 2015).

The targets, estimated values and statistics of the *availability* within the alternatives are presented in Table I. The target for the *availability* figure has been defined, for instance, by the National Public Safety Telecommunications Council (NPSTC, 2014), who defines the target for land mobile radio service *availability* as 99.999 per cent for a local geographical area (Table I). In the study, which was made for the European Commission by SCF Associates Ltd (2015), it was concluded that "PPDR networks should be available at least 99.99 per cent of the time".

"For the Finnish PSS mobile network, which is covering the whole sparsely-populated country, the achievable and feasible service availability target could be 99.9 per cent" (Peltola and Kekolahti, 2015). This *availability* value can be achieved by *dedicated* PPDR networks, if the power supply and communication links are protected in critical areas, real-time traffic monitoring is implemented and *commercial* networks are used as a back-up (Peltola and Kekolahti, 2015). The 99.9 per cent *availability* level means 9 h *unavailability* time in a year, which may be acceptable for PPDR users. However, the range of 99.3-99.5 per cent *availability* corresponds 61-44 hours of non-service time which may not be acceptable to Finnish society.

Table I Targets, estimates and statistics of availability in dedicated/commercial networks

Source of availability figure	*Availability (%)*	*Unavailability (%)*	*Downtime in a year*	*Remarks*
Targets				
NPSTC target[a] for PPDR	99.999	0.001	5.3 min	
Study for European Commission (SCF Associates)[b] for PPDR	99.99	0.01	53 min	
Dedicated BB network-achievable[c]	99.9	0.1	8.8 h	
Estimates				
Dedicated BB network-estimated[c]	99.1	0.9	79 h	
Commercial BB network-estimated[c]	98.8	1.2	105 h	
Dedicated BB network-with back-up networks[c]	99.5	0.5	44 h	Commercial networks working as back-ups
Commercial BB network-with back-up networks[c]	99.3	0.7	61 h	Other networks working as back-ups
Statistics				
Dedicated NB network-statistics[c]	98.9	1.1	96 h	
Commercial BB network-statistics[d]	99.2	0.8	70 h	Congestion by high traffic not included in statistics

Notes: [a]NPSTC (2014); [b]SCF Associates (2015); [c]Peltola and Kekolahti (2015); [d]Viestintavirasto (2013)

4.2 Exceptional non-availability periods

The annual *availability* figure can be within the expected limits, e.g. better than 99.9 per cent, but the length of a single period of non-*availability* may take longer than society is prepared to accept, e.g. longer than 2 h. The effect of this can be diminished by adding controls (Peltola and Kekolahti, 2015), which shorten the non-*availability* times or ensure at least that key services continue to be available.

When looking for the *availability* targets from the service perspective, mobile services can be divided into three categories depending on their criticality from the emergency organisation's point of view (Table II and Figure 3):

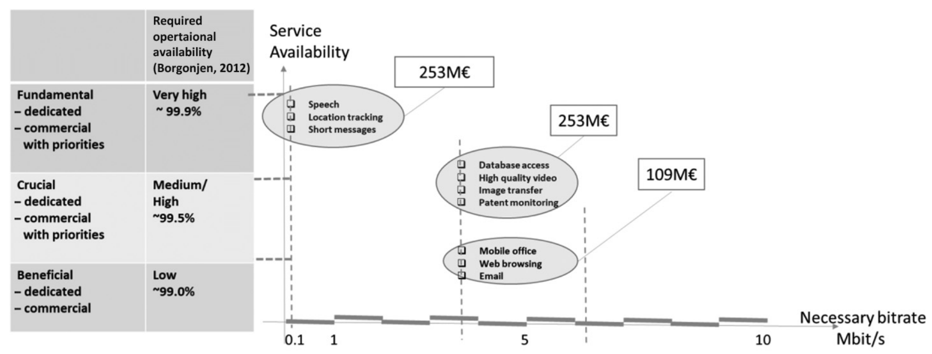
1. *fundamental* services, i.e. historically those basic mobile services viewed by emergency organisations as their life assurance, e.g. push-to-talk, short messages or GPS-based services with an uncompromised availability in all situations targeting very high, i.e. at least 99.9 per cent *availability* (Peltola and Kekolahti, 2015);

Table II Key emergency team applications and corresponding network support

PPDR network applications offering[a]	*Effects on the operation*	*Operational availability required*[5]	*Supported by* *80 kbit/s (50 kHz channel)*	*0.5-4 Mbit/s*	*5-10 Mbit/s*
Fundamental services – availability target of the service 99.9 per cent (8.8 h total downtime per year)					
Voice communication					
Group call, Individual call	Essential for operations	Very high	Yes	Yes	Yes
Location data					
Emergency centre communication, GPS	Faster location arrival	Very high	Yes	Yes	Yes
Operational information					
Mobile command and control	Closest patrol found, situation awareness	Very high	Yes	Yes	Yes
Crucial services–availability target of the service 99.5 per cent (44 h total downtime per year)					
Operational information					
Patient monitoring	First aid possibility	High	–	Yes	Yes
Multimedia					
Video on location, photo	Situation awareness, "Third" man	High	–	Yes	Yes
Automated person identification in video	Person identification	Medium/High	–	Yes	Yes
Online database enquiry					
Information database, download of maps and building drawings	Fast access to location documentation	Medium/High	–	Yes	Yes
License plate video tracking	Automatic plate checking, runaway identification	Medium/High	–	Yes	Yes
Beneficial services–availability target of the service 99.0 per cent (88 h total downtime per year)					
Office applications					
Mobile office	No main office visit, fast reporting	Low	–	–	Yes

Note: [a]Borgonjen (2012)

Figure 3 Services with availability, bitrate and socioeconomic values shown for mobile service classes (*Fundamental, Crucial, Beneficial*)



Source: Borgonjen (2012)

2. *crucial* services (*BB mobile services* with a high availability requirement) include patient monitoring, video on location, photo, automated person identification from video and information database, download of maps and building drawings as well as license plate video tracking – the achievable availability target for these services based on earlier analysis of BB networks (Peltola and Kekolahti, 2015) and network statistics (Viestintavirasto, 2016) could be 99.5 per cent, if the networks duplicate each other; and

3. *beneficial* services (BB best-effort mobile service with a more relaxed availability requirement to manage daily routines) which accept the *availability* that the existing *commercial* network are capable of supporting, i.e. 99.0 per cent based on earlier analysis of BB networks (Peltola and Kekolahti, 2015; Viestintavirasto, 2013).

The classification of services would make it possible to choose an optimal deployment for the service so that the utilisation of various services does not affect the availability of other services. It would also facilitate the valuation of services and, based on that, drop low value services during emergency cases to prevent congestion beforehand. This would make the management of the access rights simpler and make it easier to ensure a minimum service level during serious emergency events.

5. Socioeconomic value

5.1 The socioeconomic value of the broadband public protection and disaster relief mobile information technology services

The *socioeconomic value* of the BB PPDR mobile IT service in Finland has been estimated in three different ways:

1. estimation based on the methods of calculation used in past studies (Grous, 2013; Minehane *et al.*, 2014);

2. calculation of savings gained from improved performance within the Finnish emergency organisations by estimation of real savings in operational processes if a BB PPDR network is available; and

3. calculation of how much the entire costs from the emergency services sector of society could be reduced with a BB PPDR network.

The first method of calculation: Estimation based on the studies of Grous (2013), the *socioeconomic value* is approximately €94/citizen/year. According to the calculation method used in the study of Minehane *et al.* (2014), the *socioeconomic value* is €40/citizen/year.

The second method of calculation: Peltola and Martikainen (2012) have come to the conclusion that the Finnish police will save €1.4m/year using the *BB mobile service* in traffic accident operations in the Helsinki Metropolitan region, which covers about 1.5 million inhabitants. The savings are due to better performance in police operations. Extrapolating these savings to all operations and to other PPDR mobile users, the calculation suggests that the savings in the whole country when utilising *BB mobile services* would be €41/citizen/year.

The third way of counting: Calculations are done to examine the key costs of the existing Finnish PPDR sectors and how much the entire costs from the emergency services sector of society could be reduced through implementation of a BB PPDR network. In Finland, the main costs linked with PPDR operations amount to more than €7,000m annually (Peltola and Martikainen, 2012). For purposes of comparison, "the UK police may be able to achieve productivity gains of 5-20 per cent savings" by using mission critical BB communication (Grous, 2013). Based on that, the savings that mobile BB yields in Finland are expected to be 5 per cent of all the existing costs linked to the PPDR agencies sector – in this case amounting to a sum of more than €350m, i.e. €65/citizen/year.

Based on the reference cases (Grous, 2013; Minehane *et al.*, 2014), the estimated performance improvement and Finnish PPDR-sector costs, the *socioeconomic value* of the Finnish PPDR mobile IT service is €216-508m/year in Finland. With a population size of 5.4 million people, this amount equates to €40-94/citizen/year. In the analysis presented in Table III, the mean value is used, i.e. €362m/year.

5.2 Splitting socioeconomic value between fundamental, crucial and beneficial services

The annual costs of the existing NB PPDR mobile service are about €22m/year (Peltola and Pesonen, 2014). Accordingly, the monthly NB costs per user are about €50, anticipating 37,500 users. As said, PPDR organisations also utilise commercial BB networks, where the monthly user fee is €30-35/month/user corresponding to the level of service that is somewhere between *fundamental* and *beneficial* service. Accordingly, the existing total monthly costs per user are about €85; however, the services have some amount of overlapping in their offerings.

We can expect that the new BB PPDR mobile network should not result in higher costs per user with newer technology than the existing mobile systems. We can also expect that the value of services would be in line with the mutual tariffs related to these services.

The costs of the *beneficial* service users should not exceed the low fee of the typical mobile user, because the service is possible to supply with a standard best-effort commercial network,

Table III Annual *socioeconomic value* of BB mobile it for PPDR per citizen in Finland

Basis for estimation	Socioeconomic Value *(€) per citizen per year*	Socioeconomic value *(million €) per year*
Reference studies		
Grous (2013)	€94	€508m
Minehane *et al.* (2014)	€40	€216m
Based on improved efficiency savings		
Based on the estimation of operational performance improvements in police organization[a]	€41	€221m
Value definition based on the PPDR expenses of the society in Finland[a]		
5 per cent savings in all costs	€65	€351m
Estimation range	€40-94	€216-508m

Note: [a]Peltola and Martikainen (2012) i.e. in the range of €15/month/user when taking into account the volume discounts. This means that the costs to supply *fundamental and crucial services* should not be more than €70/month/user. Because the *fundamental* services are seen as a form of life assurance to the emergency organisation and those services have been the key tool for authorities so far, their value cannot be smaller than that for *crucial* services, although the latter supplies a long list of attractive applications which improve and ensure the emergency operations. For this reason, it is assumed that both services have equal *socioeconomic value.*

As counted, the *socioeconomic value* of the BB PPDR mobile IT services, i.e. the value of *crucial plus beneficial services* is €362m. If so, then the value split between all services is the following: *fundamental* services €253m; *crucial* services €253m; and *beneficial* services €109m (Figure 3).

6. Costs

6.1 Costs of dedicated public protection and disaster relief broadband mobile network

The base PPDR BB mobile operator administration and operation costs are taken into account by including the sum which is equal to the total operating costs of the existing NB operator. The additional investment and operations costs including base stations, the core network, the network management, spectrum costs (€22m; based on the 700 MHz auction in 2016), network planning, building and commissioning are based on information from telecom vendors and operators (Cassidian Oy, 2012; L M Ericsson Ab Oy, 2012; Nokia Siemens Networks Oy, 2012; Suomen Erillisverkot, 2012).

The annual discounted figures (equal over 10 years) are calculated from the net present value (NPV). The NPV is calculated based on the cash flow and using the discounting interest rate of 3 per cent. The total annual discounted costs of the networks in five different regions are shown in Table IV.

6.2 Costs of using commercial public protection and disaster relief broadband mobile networks

The *cost* of the *commercial* PPDR BB mobile network are assumed to be the same as the subscriber fees collected by the operator. Table V contains the costs of subscriber fees. The number of users has been increased from the existing number (37,500) to 50,000, because with LTE technology the platform of the terminals can be based on commercial devices which brings a major part of the functionality implemented for ordinary subscribers; the original estimation of the number of users in the Finnish NB PPDR network was 50,000 subscribers (Rantama and Junttila, 2011). The subscriber fee that is used in the commercial network is €55/user/month (in sensitivity analysis, chapter 7, €40-70 will be used), which consists of a heavy business user fee, i.e. €35/user/month (Viestintavirasto, 2017); improvements to power supply protection (€10/user/month) to equip 2,800 base stations with 6 h of battery capacity so that vehicle communication can be guaranteed (Peltola and Hämmäinen, 2015); and the

Table IV Annual investment and operating costs of LTE750 dedicated networks in five regions (K€)[a]

Cost item	*Helsinki*	*Uusimaa*	*Pirkanmaa*	*Pohjois-Savo*	*Kainuu*
No. of base stations	30	190	150	150	120
Investments, first year					
Network	1,490	8,203	6,370	6,370	5,110
Spectrum costs	2,425	6,309	2,002	1,001	331
Annual operating costs					
Network	627	2,671	2,103	2,106	1,701
Total annual discounted costs	1,095	4,436	3,168	3,067	2,422
Total annual discounted costs per km^2	7.266	0.773	0.380	0.265	0.175

Note: [a]Peltola and Hammainen (2015)

Table V	PPDR subscriber fees of commercial networks in five Finnish regions per km^2 (K€)				
Commercial 3G/LTE	*Helsinki*	*Uusimaa*	*Pirkanmaa*	*Pohjois-Savo*	*Kainuu*
Subscriber fees per year	6,164	11,235	2,520	1,406	531
Total annual costs per km^2	28.672	1.174	0.174	0.069	0.022

expected availability improvement costs (€10/user/month) to decrease availability risk – i.e. breaks in transmission and priority functionality. The annual *costs* per km^2 of the three network variants –the *dedicated* BB network, the *commercial* BB network and the *dedicated* NB network – are shown in Figure 4 as a function of population density. As can be seen, the *costs* of the *dedicated* and *commercial* alternatives are equal when the population density is about 70 persons per km^2.

7. *NetBenefits* of mobile service variants

The analysis model for PPDR mobile network valuation is based on the conceptual causal loop diagram model shown in Figure 1. The analysis model (Figure 5) is made using the Vensim-tool, and in the analysis four network alternatives are compared (Figure 6). The alternatives are the existing NB PPDR network + the *commercial* best-effort service combination; the *commercial* BB network fulfilling QoS requirements; the *dedicated BB* network; and the hybrid BB network version - *dedicated* or *commercial* network – depending which one created the highest *socioeconomic value* in the area under study.

The alternatives are compared by calculating the *NetBenefits* of the service values. As mentioned earlier, the studied network case is taken from Finland (Figure 2). The reference cases, including the cost calculations are the same as those used in the earlier study (Peltola and Hammainen, 2015); the used number of users is 50,000.

Three thresholds can be found in Figure 6: the point (45 persons/km^2) when the existing NB + commercial best-effort LTE combination exceeds the *NetBenefits* of the *commercial* BB network; the point (65 persons/km^2) when the *dedicated BB* network exceeds the *NetBenefits* of the *commercial* LTE network; and the point (80 persons/km^2) when the *dedicated* network exceeds the *NetBenefits* of the existing NB + commercial best-effort LTE combination.

Figure 4 Annual *costs* per km^2 of network variants as a function of population density

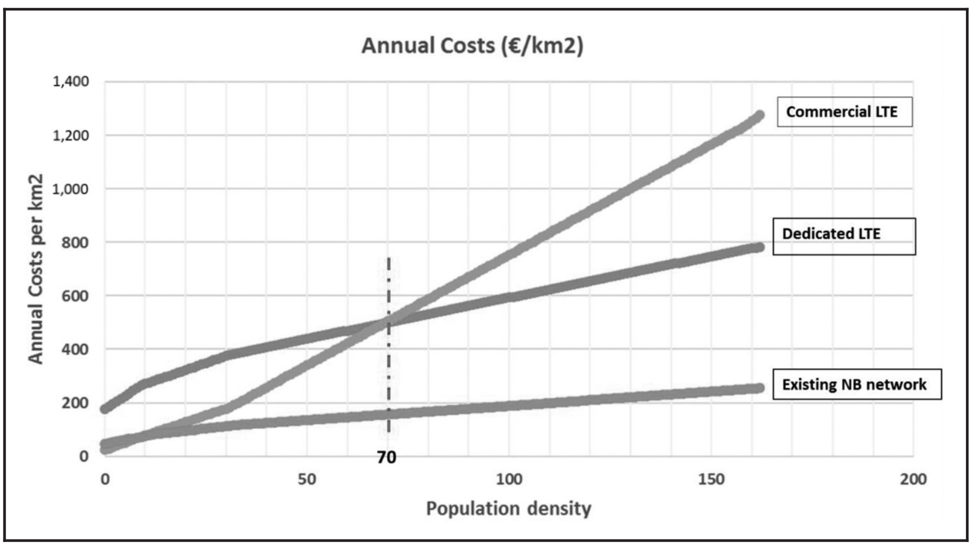
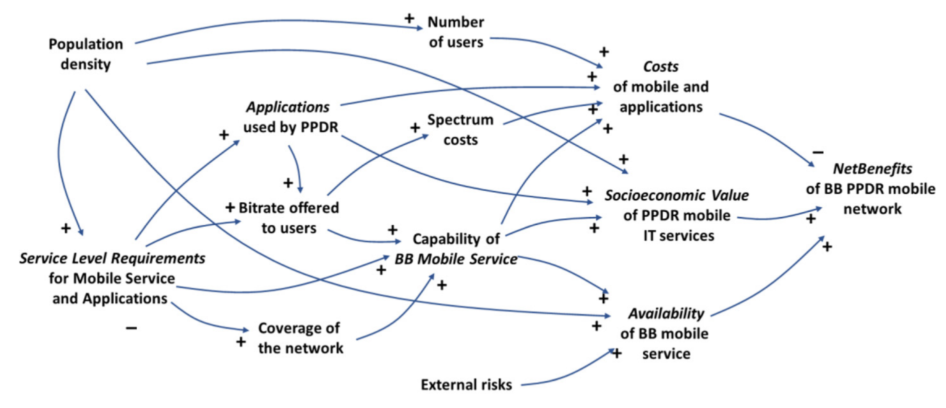
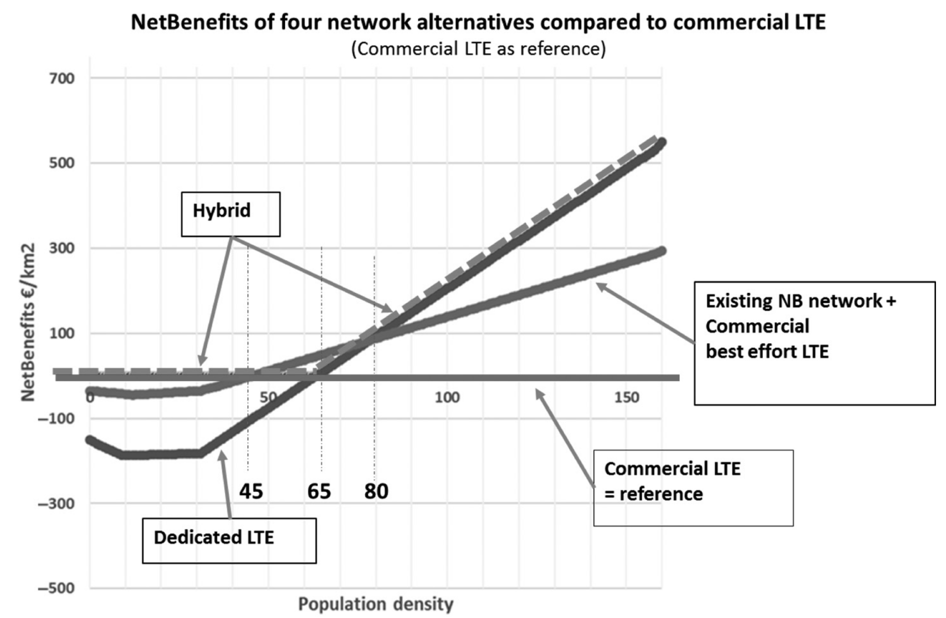


Figure 5 Causal loop diagram of BB PPDR network valuation



Source: According to Sterman (2000)

Figure 6 PPDR mobile network alternatives compared to commercial network

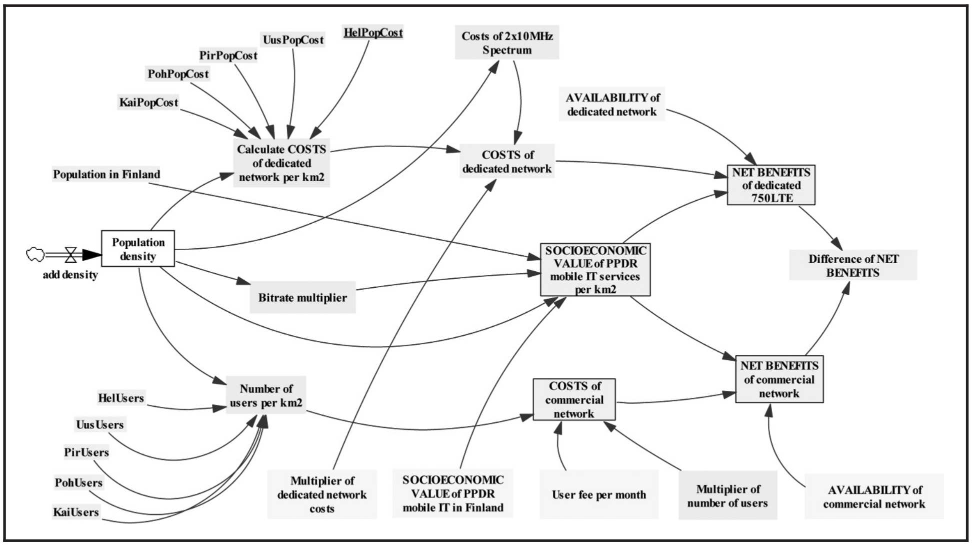


Network Type	Availability and Socioeconomic Value
Dedicated NB + best-effort commercial LTE	99.9%/253M€ + 99%/362M€
Commercial LTE network	99.5%/615M€
Dedicated LTE network	99.9%/615M€
Hybrid network	(Sparsely: 99.5%+Densely: 99.9%)/615M€

7.1 Sensitivity analysis

The Monte Carlo simulation is done to compare the two most interesting alternatives, the *dedicated BB* network and the *commercial* LTE network. The Monte Carlo analysis calculation is performed using the Vensim-tool (Ventana Systems, 2013), the analysis being based on the model shown in Figure 7. The variable "Difference of NET BENEFITS" in Figure 7 defines the difference in *NetBenefits* values for the *dedicated* and *commercial*

Figure 7 Sensitivity analysis simulation model



networks investigated in the case studies. The sensitivity analysis results are shown in Figure 8.

The sensitivities of five variables are analysed (Table VI): the monthly subscriber fee in *commercial* networks; the *availability* of the *dedicated* network; the *availability* of the *commercial* network; the *costs* of the *dedicated* networks; and the *socioeconomic value*. The applications variable is omitted from the model because the influence is the same on both alternatives.

Figure 8 *NetBenefits* of dedicated network minus *NetBenefits* of commercial network sensitivity analysis: Monthly fee of users €40-70/month availability of dedicated network 99.1-99.9 per cent; availability of commercial network 98.0-99.5 per cent; costs of dedicated network 100-120 per cent socioeconomic value €216-508 m

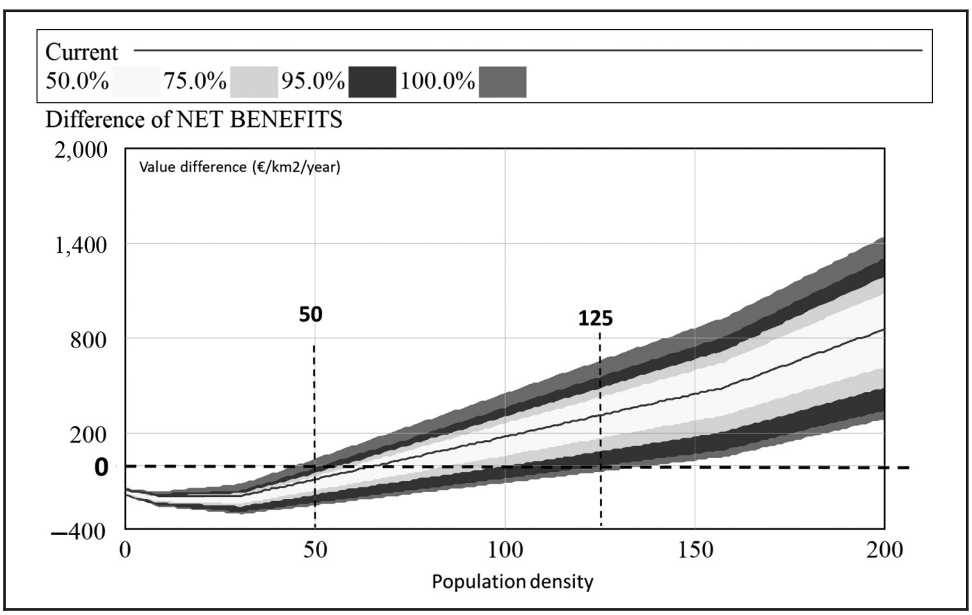


Table VI Parameters of the sensitivity analysis

Parameters	*Nominal value*	*Variation of parameters*	*Variation of threshold value (persons/km^2)*	*Basis for variation*
Monthly fee of users	€55/month	€40-70/month	50-95	Costs to complete higher availability requirements/ uncertainty of costs
Availability of dedicated network	99.1%	99.1-99.9%	60-68	Availability improvements
Availability of commercial network	98.8%	98.0-99.5%	60-70	Cyber attacks, network blocking; priority functionality, backup networks
Costs of dedicated networks	100%	100-120%	70-85	Uncertainty in network plans
Socioeconomic Value	€362m	€216-508m (€100-1,000m)	66-67 (64-69)	Uncertainty in estimations
		Total effect	50-125	

The table consists except the nominal values of the parameters, it also shows variations of parameters and effected threshold values when a single parameter varies as well as the threshold variation if all parameters vary at the same time.

The high monthly subscriber fee (€70) is expected to be the result of the remedy fee risk caused by the uncertainty of the service availability. The availability improvements may require more investments than the modest incomes that a few PPDR subscribers can provide; also, the large amount of location data transportation (Saijonmaa, 2009) in the network may increase user fees. The low monthly subscriber fee (€40) is expected to result from tough competition between the commercial operators.

Cyberattacks are an increasing threat to all *commercial* networks (Balmas, 2013). Therefore, in the sensitivity analysis, the lower *availability* value (98.0 per cent) for the *commercial* network is used; also, the congestion of the network because of mass events with high communication traffic may decrease the level of *availability*. The availability figures used in the sample case are for the *dedicated* services from 99.1 to 99.9 per cent and for the *commercial* services from 98.0 to 99.5 per cent.

In the sensitivity analysis the *costs* of the *dedicated* networks have been increased by 20 per cent compared to the reference indicators; this is done to ensure that the *costs* of the *dedicated* network are not underestimated – although the base cost, equal to the existing NB operation costs, is included. This will also compensate for any uncertainty there may be in the numbers of base stations. In the sensitivity analysis the variation of *socioeconomic value* is broad, because the estimation of its value is inexact.

The results of the analysis – *NetBenefits* of the *dedicated* network minus *NetBenefits* of the *commercial* network – are shown in Figure 8. According to the sensitivity analysis and to 95 per cent probability, the *commercial* network is most preferable until the *threshold* point when the population density reaches 50-125 persons/km^2. After that point, the *dedicated* network is more appropriate.

8. Discussion

8.1 Spectrum

The solution which uses the 700 MHz band would be preferable, because USA, UK, Canada and France have already selected that band for their own PPDR networks (FCC, 2012). Keeping to this spectrum would result in volume benefits. The shared spectrum band is proposed in this paper, i.e. the spectrum would be allocated for public safety users in urban areas, whereas in rural areas, it would be freely usable by any mobile subscriber. With such an arrangement, the PPDR agencies could have a dedicated network with high availability in urban areas. The *commercial* operators would have low frequencies available in the countryside, where those frequencies are especially valuable to them; in urban areas the increasing need for good indoor coverage requires the network architecture to have small cells. Nonetheless, plans to release the whole 700 MHz band for the use of *commercial* mobile BB have been criticised (Delgado, 2015).

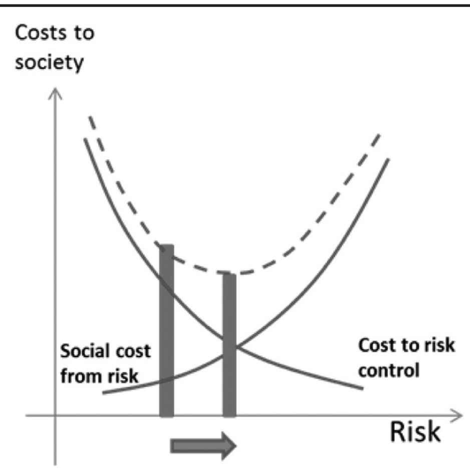
8.2 Targeting higher availability

A question may be risen: Would it be useful to take in hardening to move to four nines in *availability*? The optimum for the *availability* (=1-Risk) can be identified if the risks that threaten the *availability* of the s*ervice* are understood also as a v*alue* of the diminished risks (Figure 9). By comparing the various options for risk control, investments can be more effectively targeted towards appropriate objectives. Three key controls are taken into account to improve the *availability* (Peltola and Kekolahti, (2015). They calculated the additional *socioeconomic value* arising from the proposed changes (i.e. 1,000 additional aggregates, 1,200 duplicated radio links and the real-time traffic monitoring system) for the dedicated network case. The *availability* was improved (= risk lowered) from 99.1 to 99.8 per cent, which results in increase the net *socioeconomic value* of €3.5m, when the nominal *socioeconomic value* is €500m. However, the achieved additional *socioeconomic value* does not compensate for the annual costs (€7.0m/year) that must be made to realise those benefits. Therefore, it must be concluded that any *availability* target of the PPDR mobile system higher than 99.9 per cent is difficult to justify based on increased *NetBenefits*. Nevertheless, the values of the society may see additional investments feasible.

8.3 Effect of population density on NetBenefits

Commercial operators use flat national user fees. Therefore, in sparsely populated areas, the *commercial* operators subsidise monthly user fees, which means that *commercial* mobile networks are competitive to supply *BB mobile service* for PPDR organisations – although the *availability* values of such networks are lower than within *dedicated* networks. As the building

Figure 9 The cost of risk vs the cost of control



Source: Modarres (2006)

and maintenance costs of such networks are proportional to the coverage area, the costs per citizen in rural areas are high.

In densely populated areas, on the contrary, *commercial* operators overcharge monthly user fees because the costs per user of the network are low due to high customer volumes. Therefore, the *dedicated* mobile networks are competitive to supply *BB mobile service* for PPDR organisations in urban areas. Additionally, the higher availability value creates an increased *NetBenefits* value in the environment where the number of incidents requiring the help of the emergency organisations is high.

Table VII compares the population densities of various regions in Finland and the annual operations of the police. The percentage shares follow each other quite well, except where the population is high – in these regions, the number of operations intends to grow. That means the *socioeconomic value* of the PPDR network is slightly higher in densely populated regions than expected. This does not, however, alter the main results of the analysis, because the value grows in both alternatives.

8.4 Voice communication requirements in public protection and disaster relief mobile networks

In PPDR push-to-talk communication, the time, when the tangent has been pressed on the phone until the moment when the speech connection is on, has to be less than 500 ms (Peltola, 2013). The latency time in LTE networks is short enough to support this requirement, but the high communication peaks during emergency situations and the behaviour of the packet switch-based voice communication may cause long delays during high traffic situations. Therefore, the behaviour of QoS mechanisms – if with the *commercial* PPDR LTE networks the 2G/3G networks are intended to complete the network coverage – has to be carefully reviewed. If the latency time in 2G and 3G networks does not fulfil the requirements, the *commercial* service cannot be based on the utilisation of these technologies.

8.5 Utilising existing TETRA or TETRAPOL narrowband with broadband public protection and disaster relief mobile networks

If *BB mobile service* will not be implemented using *dedicated networks*, there are some doubts as to whether the *commercial* networks are capable of securing the *availability* which fulfils the requirements of mission critical organisations. Moreover, there are also grave concerns about how well the priority functionalities work and whether the priority functionalities are even supported by the operators (TCCA, 2017). So far, the *availability* supplied by the *dedicated* NB PPDR networks has been within the acceptable level, i.e. 99.5-99.9 per cent including the backup service offered by *commercial* networks and the insurance that mass events have no effect on the *dedicated* network. In *commercial* networks, the main risk situations are incidents when all mobile networks become out of service at the same time, e.g. a common power supply break, high communication peaks caused by emergency situations or attack by hackers (DW,

Table VII Annual number of police operations in Finland IN YEAR 2014[a]

Region	*Population*	*Population density, persons/km²*	*Percentage share of population %*	*No. of police operations*	*Percentage share of operations %*
Whole country	5,400,000	16	100.00	1,046,888	100.00
Helsinki	600,000	2,785	11.11	168,057	16.05
Uusimaa	1,550,000	162	28.70	353,378	33.76
Pirkanmaa	490,000	34	9.07	82,133	7.85
Pohjois-Savo	250,000	12	4.63	49,403	4.72
Kainuu	81,300	3	1.51	16,205	1.55

Note: [a]PolStat (2015)

2016). During the recent Brussels' bombings in 2016, the *commercial* mobile networks in the city centre were congested or the service seriously degraded for 2-5 h (Lezaack, 2017).

If in Finland, the nationwide NB PPDR mobile network would be maintained in parallel with the BB PPDR network (Airbus, 2017a) to ensure high *availability* of *fundamental* services, the additional annual costs of the nationwide NB PPDR mobile service would be €22m/year. The NB network would only generate (99.9-99.5 per cent) $\times$ €253m = €1.0m additional *socioeconomic value* (over the whole nation). However, if the *availability* improvement would be concentrated in the densely populated area, the utilisation of the parallel NB network in district areas might be feasible. For instance, in the Helsinki area the annual costs of a NB PPDR network are about €1.3m/year, so the saving of an additional human life (€2.2 m) (Finnra, 2006) would more than compensate for the additional annual costs. As a reference, annually in Finland about 100 persons die as a result of homicide and about 2,000 in accidents (Statistics Finland, 2011) – about 11 per cent of the total Finnish population lives in Helsinki. A conclusion might be that in a certain densely populated part of the country, maintaining the existing NB network services would, in fact, be feasible.

8.6 Impact of Internet of things on availability of mobile networks

Some IoT-based applications (IoT – Internet of Things) require tighter availability requirements from mobile networks than have been required so far, e.g. using IoT in intelligent transportation requires high availability, high security and short response times. Suo *et al.* (2012) have studied what the usage of IoT will mean and have come to the conclusion that "the development of IoT will bring more serious security problems" – which obviously will all have to be resolved. Mobile networks, which are capable of supporting critical IoT applications, will also meet requirements of PPDR mobile platforms. Additional investments in the *commercial* networks – to fulfil the needs of IoT applications – will increase the attractiveness of such *commercial* networks as platforms for the PPDR mobile service. However, there are additional security issues that arise from the higher number of connection points in networks. This increases the threat of cyberattacks, which have to be treated at the same time.

8.7 Hybrid solution

In the hybrid solution – i.e. the BB PPDR mobile network is formed of *commercial* BB and dedicated BB networks – the same frequency band, e.g. one of the 700 MHz bands, is allocated to the *commercial* operators in rural areas and for the *dedicated* network in certain specific urban areas. The main value of the 700 MHz band for *commercial* operators is its advantages when building networks in rural areas – the 700 MHz band needs fewer base stations in comparison to. In urban areas, the overload of the mobile network in emergency situations during mass events is a risk. For this reason, a *dedicated* band of the 700 MHz spectrum would be feasible to reserve solely for PPDR users in urban areas.

9. Conclusions

Socioeconomic value is a common measure for making the valuation of governmental investments; population density has a strong impact on the optimum deployment alternatives as the *socioeconomic value* is directly proportional to population density.

The flat nationwide fee of the mobile users means that the users are subsidised in sparsely populated areas – and overcharged in densely populated areas. This is the main reason why the *commercial* network seems to be more feasible in rural areas – and the *dedicated* network in urban areas. Based on the sample study, the *commercial* network is most preferable up to the point when the population density reaches 50-125 persons/km^2; after that point, the *dedicated* network is more appropriate due to the lower *costs*.

The value of *availability* also affects the net *socioeconomic value*, but because the major part of the value is created during "normal circumstances", the differences of net *socioeconomic value* caused by different *availability* are within the magnitude of tenths of a per cent, which is marginal. However, if we review the *unavailability* times instead of the *availability* figures, the differences are quite significant. For instance, a figure of 99.9 per cent *availability* means 9 h of *unavailability* time, but 99.5 per cent *availability* equates to 44 h of non-service time; a service break of 9 h in a year may be acceptable but not breaks total of almost two days.

When *commercial* networks are used as a base for the *BB mobile service*, certain improvements should be considered to ensure the readiness of *commercial* networks to serve as PPDR mobile networks: to secure the priority functionality in *commercial* mobile networks; to review the optimum way of ensuring power supply protection for the base stations so that at least vehicle coverage is guaranteed during all kinds of power supply disruptions; allow PPDR subscribers the exclusive use of one of the 700 MHz spectrum bands in restricted, critical areas, i.e. use of the shared spectrum; and to extend use of the existing NB PPDR network in the areas where the communication *availability* is crucial.

The conclusions of the paper are of most relevance for countries with highly contrasting population-density settings of (sparse rural/dense urban populations), such as Finland. When making the analysis for other countries, the results are likely to be similar or the same, along similar lines – however, the threshold value between the two network types depends on the values of some country specific parameters, which have to be redefined.

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Corresponding author

Matti Peltola can be contacted at: matti.peltola@mapelcon.fi