

# INTERDISCIPLINARY DESCRIPTION OF COMPLEX SYSTEMS

## Scientific Journal

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# ON DEVELOPMENT OF INFORMATION COMMUNICATIONS IN HUMAN SOCIETY

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Regular article

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## ABSTRACT

Information is very important. Information is also very complicated, making that people have no common understanding and conclusion for the nature of it up today. There are too many papers and some books to describe information; however it is rather difficult to find the description and analysing for the whole history of information from the advent of human beings to the present day. Two parts of information in prehistoric period and the time interred divinization are described. Every part is separated according to several succeeded stages for description. It is near impossible to describe in detail such entire historical facts of information in human society in a paper, so the description and discussion is focused on their comprehensiveness and integrity. By knowing and analysing all these solid historical facts of information, some relative issues e.g. “did information age really exist in the development of material civilization in human society” can be recognized easily.

## KEY WORDS

information, history of information, information communication, matter, substance civilization, six-stage theory

## CLASSIFICATION

JEL: B10, D83

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## INTRODUCTION

Near everybody knows the importance of information because nobody can leave the information and its communications. From the moment human beings leave their mothers' bodies, they use crying to attract the attention of the parents. Especially, they proclaim to the world in a high-profile way: I am coming. Except a person has died otherwise he/she is never left information communications. We use every emotion that we portray on our faces, the movement of our hands, the way we look at someone and our speech to communicate our ideas to others. In fact all aspects of our life such education, study, work, social, movement, travel, love, etc. need information and its communications.

However, do we understand the history of information for humankind? How does the development of information communications in human society progress from the advent of human being to the present day? A lot of papers on the field of information subject have published; no one has answered these problems with the solid historical facts completely and comprehensively. Fortunately there is a good book of *The information: a history, a theory, a flood* by Gleick [1], but it is not a real book of the history of information. From the book people are rather difficult to understand a rather complete history of information because the stories are more than history in it. Similarly there is a good paper of *History of information science* [2], in which the authors write "We have treated IS (information science) inclusively in two senses. First, we include specialized applications areas, such as archival, library, and corporate information services as specialties within a broad view of IS rather than specialties outside of it. Second, we agree with VAKKARI (1994) that it is misguided on theoretical grounds (as well as difficult in practice) to separate the theory of library science and of documentation from that of IS." That is to say that that paper is still not mentioned the whole history of information as we want.

That is why the aim of the article is focused to discuss such problems in order to sketch out the history of the entire information communications of human beings. Then people can know the history of information from the advent of human beings to the present day. Information is accompanied with the whole time of humankind, never stopped, never regressed, always progress along with human development. Of course, we do not want to describe the history of information for human society in detail, but just to sketch out the whole information history for human beings completely and comprehensively. Two parts are discussed separately: prehistory and the time of civilization. Every part is separated according to several succeeded stages for description.

Then we will analyze the whole historical facts of information and see what they can tell us.

## THE NATURE OF INFORMATION

A lot of papers and books have discussed the nature of information in the literatures. It is obviously that the historical development of information is closely related to this issue, so knowing the nature of information is necessary. Here we just cited only few papers discussed the issue early in 1920 years. Before such discussion, we must point out what mentioned Mingers and Standing [3]. These two authors said that even up to 2017 "there is still not an agreed and explicit conceptualization or definition of information" in the world. In addition, there are more than 200 information definitions available in the literature according to the statistics by Hu and Wengen [4]. This situation indicated that the issue of the nature of information is very complicated so that there is no united definition of information up today.

Early in 1924 Nyquist [5] published a paper in which he derived a formula of the speed of transmission of intelligence  $W$ :

$$W = K \log m, \quad (1)$$

where  $m$  is the number of current values, and,  $K$  is a constant. According to Nyquist, the meaning of the speed of transmission of intelligence is that the number of characters, representing different letters, figures, etc., which can be transmitted in a given length of time assuming that the circuit transmits a given number of signal elements per unit time.

Four years later Hartley published another paper [6], and he also derived a formula for the amount of information associated with  $n$  selections:

$$H = n \log s, \quad (2)$$

in which  $s$  is the number of possible symbols available at each selection in a transmission, and  $n$  the number of selections of primary symbols. Equation (2) shows that the practical measure of information is the logarithm of the number of possible symbol sequences. Pierce [7] evaluated Hartley's work as follows: "his idea of defining the quantity of information as the logarithm of the number of symbols seems very modern, but its success in elucidating knotty problems was not great. It is Shannon's feeling, and mine, that Nyquist's work was more fruitful". In addition, Rioul and Magossi [8] also evaluated Hartley's work. They proved that some "historical" statements in the literature for the relationship between "Hartley's rule" and Shannon's formula (will be described below soon) are somewhat wrong, because their careful calculation shows that "Hartley's rule" in fact coincides with Shannon's formula. They found that this mathematical coincidence by deriving the necessary and sufficient conditions on an additive noise channel such that its capacity is given by Shannon's formula and construct a sequence of such channels that makes the link between the uniform (Hartley) and Gaussian (Shannon) channels.

In 1929, Szilard [9] in his famous paper published his information definition i.e. information is entropy. Szilard wanted to understand the "Maxwell's demon" and how much energy the demon would consume in its operations, so he designed a thermodynamic "gedanken experiment". Such experiment was called Szilard's engine later in the literature. From the mathematical calculation Szilard obtained the mean value of the quantity of entropy  $S_A$  and  $S_B$ , per measurement as:

$$S_A = -k \log p(T_0), S_B = -k \log q(T_0), \quad (3)$$

where  $p(\cdot)$  and  $q(\cdot)$  are the probabilities which are in the lower or upper state respectively because Szilard only evaluated these expressions for the very simple case of a body with only two energy states; a lower and a higher state. In (3),  $T_0$  is the temperature of the heat reservoir.

After near 20 years, 1948 Shannon in his paper of [10] wrote that "If the number of messages in the set is finite then this number or any monotonic function of this number can be regarded as a measure of the information produced when one message is chosen from the set, all choices being equally likely". Then, Shannon asked: "Can we define a quantity which will measure, in some sense, how much information is 'produced' by such a process, or better, at what rate information is produced?" After some mathematical derivation, he obtained:

$$H = -K \sum_{i=1}^n p_i \log p_i, \quad (4)$$

for the definition of information. He said that "Quantities of the form  $H = -K \sum p_i \log p_i$  (the constant  $K$  merely amounts to a choice of a unit of measure) play a central role in information theory as measures of information, choice and uncertainty". Quantity  $H$  will be recognized as that of entropy as defined in certain formulations of statistical mechanics. That is to say that Shannon defines information as the entropy in the statistical physics. Here  $K$  is a positive constant,  $p_i$  is the probability of a system being in cell  $i$  of its phase space. How do we measure information? It uses bits. According to Shannon [10] "The choice of a logarithmic base corresponds to the choice of a unit for measuring information. If the base 2 is used the

resulting units may be called binary digits, or more briefly bits, ... A device with two stable positions, such as a relay or a flip-flop circuit, can store one bit of information.  $N$  such devices can store  $N$  bits, since the total number of possible states is  $2^N$  and  $\log_2 2^N = N$ ." Therefore, Shannon was the first user to use bit as the unit for measuring information.

It is interesting to point out that the cited above four papers all are defined the entropy using an equation, and Shannon's paper published later than near 20 years or more. Shannon pointed himself in the beginning of his paper, Nyquist in 1924 and Hartley in 1928 published important papers, building "a basis for such a theory (a general theory of communication – the author)". Of course, Shannon [10] has extended "the theory to include a number of new factors, in particular the effect of noise in the channel, and the savings possible due to the statistical structure of the original message and due to the nature of the final destination of the information". So that, a formula for measuring the average amount of information is given by Shannon, realizing the leap of communication science from qualitative stage to quantitative stage as mentioned above. That is to say that Shannon's merits must be affirmed in terms of the entropy definition of the information.

Why Shannon said that Nyquist and Hartley built a basis of information theory? The equations (1) and (2) given by Nyquist in 1924 and Hartley in 1928 evidently show such point.

However, the meaning of equation (3) is the same as that in equation (4) which means that Szilard not only correctly defines the quantity known today as information, which has found a wide use in the work of Claude Shannon and others in the field of communication science. The history fact indicates evidently that Shannon is not but Szilard is the real first man to define information using the entropy. In addition, though Shannon's paper was published in 1948 later than that of Szilard in 1929 for 19 years, but Shannon's paper did not cited the paper by Szilard. Some articles have said that it seems that the definition and theory of modern entropy only began with Shannon's article in 1948. All credit is attributed to him, which is obviously not in line with historical facts. Here we seriously point out such issue using these words in order to treat historical facts fairly.

As mentioned previously, there is a lot of definitions of information. They mutually differ, often overlap and sometimes are in conflict. Why? The concepts from various proposers are not the same. Their angles and ways of looking at the problem are not only the same. In addition, the issue is complicated. It is not easy to catch the nature. It is somewhat similar to what is said in the old story of "Blind men sizing up the elephant."

Considering the above situation, we want to propose ourselves definition of information. We do not believe that it is the best one, but just want really easy to understand the nature and the meaning because people are difficult really to catch the meanings from many existed definitions of information. Our definition of information is that information is not a substance but needs to have a physical carrier, which sends, communicates and stores messages, knowledge, data and intelligence directly or indirectly through human's expressions or hints, things they write or create as well as tools or media they used, so as to make people to perceive insight or excitement, worryment or angry, calm or indifference.

## **INFORMATION IS ALWAYS ACCOMPANIED BY THE HISTORY OF HUMAN EMERGENCE AND DEVELOPMENT**

Information and communication develop with the development of human being throughout. As the progress of civilizations of mankind, information and communications technology (ICT) can be divided two big parts separately: prehistory and the time of civilization. Every part is separated according to several succeeded stages for description.

## **PREHISTORY STAGE**

Archaeological research by White et al. in 2009 [11] found that earliest human ancestor lived in Ethiopia about 4,4 million years ago. In their paper, White et al. [11] show the ARA-VP-6/500 skeleton they found. Later on some of our ancestors went out to other areas in the world. Very recently, a group of Chinese scientists [12] proved first from their underground excavation that Hominin occupied the Chinese Loess Plateau since about 2,1 million years ago. In other words, Homo erectus went out of Africa at least before 2,1 million years. After very long time, the development of mankind entered into the so called the period of historical records. As the typical example of China, she entered into such period at about BC 2070 of Xia dynasty. That is to say it lasts more than 4.3 million years for the primitive society that mankind lived without recorded history. It is difficult to say and describe the real information for human being in the period because no historical data can be used. However, from the researching data for the communications of animals, legend stories, and some descriptions of the stage in some famous books such as [13] and [14], humankind not only have communicated using information, but such information is developed with the progress of human being. We can easily imagine that from the very beginning of period ancients transfer information such as safety, panic, intimidation, warning, courtship, food search and so on through their eyes, facial expressions, head and limb movements, voice changes, objects, simple tools, etc. More in detail, several methods can be divided as follows.

### **One is visual transmission**

The aim is to cause the attention of the other party. The methods are using gestures, mimicry, using pyrotechnics or physical objects etc. Because of only using general physical objects cannot be far from meeting the needs of human interaction, our ancients developed painting to transfer and store information. As a whole, developments in Eastern painting historically parallel those in Western painting, in general, a few centuries earlier. As example, two paintings are mentioned here. One is a rock painting found in the north-west Kimberley region of Western Australia c. 15 000 BC [15]. Another is a human head shape mouth color painted pottery bottle, which was excavated from Dadi Bay, Qinan County, Gansu Province, China at Yangshao mid by Zhang and Pengchuan [16].

### **The second is sound transmission**

The most important method of course is using mouth and language to transmit various information included storytelling. However, such method only can transfer information in a short distance. For long distance transmission, ancients used some nature or their made simple vocal tools such as bird language, bamboo blowing, blowing horn, signal drum to perform it. In hunting, in order to trap prey, primitive people imitated the sound of birds, so that the prey was not alarmed and easy to hunt. Later, it was developed to transmit hunting information with birdsong.

Bamboo flute is rather easy to prepare. Even if there are only stone knives and axes, bamboo flute is not too difficult to make in the place where the bamboo is produced. The conch is easy to pick up at the seaside. Therefore, they can be used for transmitting information in a rather larger area. Just because of such things are not difficult to make, easy to use, even up today, they are still used in many nations.

Ancients used wooden trunks to make wooden drums. The drumbeat can make different sounds, and so as to convey different kinds of information. Gleick in 2011 called the drum as “talking drum” in his book [1]. He described the ancient’s drums very vivid. He wrote that the drums of the uncivilized barbarians can travel along the river, through the quiet night, and

spread nearly ten kilometers. Such a message, transmitted from village to village, during only an hour, can go one or two hundred kilometers away.

### **The third is optical transmission**

Our ancestors must know the natural fires i.e. lightning and mountain fire. After they eaten the roasted meat by the natural fire, it is very easy to image that they are very eager to have a fire to eat cooked animal meat. After a very long time, they found finally how to make fire, which is drilling wood and rubbing stones to make fire. From unearthed cultural relics in Cross-Lake Bridge, Zhejiang Province, China, Chinese scientists certificate that at least before BC 6 000 ancient Chinese people known how to get fire with drilling wood. There were 51 pieces of wood cone unearthed [17].

Brain and Sillent [18] also proved that during their excavations of hominid-bearing breccias in the Swartkrans cave altered bones were recovered from Member 3 (about 1,0-1,5 million years ago) which seemed to have been burnt. They believed that the appearance of burnt bones in Member 3 from Swartkrans is the earliest direct evidence of fire use in the fossil record. Once our ancestors have mastered the fire, they must use fire to make lights such as Kong Ming lamps [19], flares, Beacon Tower, wolf smoke, etc. for transmitting information. We only want to say more words about Beacon Tower here. Many ancient nations in the world were used Beacon Tower, but it was more famous in China. Just mentioned the Beacon Tower built on The Great Wall, a number of Beacon Towers have built on it. The famous one is called “The First Beacon Tower”. In ancient times, on a military fortress and a road leading to a fortress, a beacon tower was built at regular intervals. When the enemy invades, the bonfire is lit, and the information is transmitted one by one. For example, in the Han Dynasty, the generals led hundreds of thousands of troops to attack the invading Huns (Xiongnu), but they used the bonfire as a signal to enter the army. In just one day, this signal was transmitted from the west of Gansu Province to the east of Liaoning Province; the distance is thousands of miles away.

### **The fourth one is language transmission**

Atkinson concluded in his paper [20] that “An origin of modern languages predating the African exodus 50 000 to 70 000 years ago puts complex language alongside the earliest archaeological evidence of symbolic culture in Africa 80 000 to 160 000 years ago”. That is to say our ancestors can speak various languages before a very long time ago; they used language to communicate naturally. So we can find many authors in their papers called as “oral communication era”. After ancients mastered language, their communications became wider and deeper. Not only the general information, but their thinking even their emotion also can be transmitted face to face. Language communication enables personal experience and knowledge to be shared by all, and the cultural accumulation of predecessors is inherited by future generations. However, language communication receiving terminal is the human auditory organ ears, the transmission effect is very limited, the information loss is large, and it is still not conducive to preservation and inheritance.

### **The fifth is symbol transmission**

Except their brain, primordial human using some symbols to enhance their memory. For example, they used knot rope and carved wood to help their memory. From the most ancients’ book in China, it wrote that primitive mankind used rope to keep records, and the later generations use the words to replace it. Such method of using rope to keep records also was used in many ancient nations in the world.

Then, Chinese ancients discovered hieroglyphics which was origin from the pictures. Early at the beginning of Xia Dynasty at 2 070 BC, Chinese ancients discovered oracle that is the earliest mature text. First, the oracle was carved on oracle bones, tortoise shells or pottery, till to the late Spring and Autumn Period, the oracle was carved onto the bamboo slips and wooden slips. So that till to 770 BC, the real books were born in China. Of course, that time was interred into the period of civilization for a long time; and we just consider the describing convention so as to add some words here.

### **The sixth is postal service in ancient times**

From the oracle bones excavated from Yin Ruins, the scientists found the earliest written record of “postal service” in China [21]. These two words were found in the report (at 1400 BC) which was written by the frontier guards to report the military situation to the emperor. It is evidently that the postal service was existence at least before BC 1400 in China. In fact, the situation should be similar for many other nations in the world. In order to describe serially and to understand more clearly, the following contents which are not belonged to the prehistory stage are still arranged here.

Since ancient mankind entered into the so called civilization era from primitive society, slavery country has been built, the ruling class created the postal station systems in order to control their countries. The so called postal station is that in order to meet the needs of the political and military activities for the government of ruling class, a post station was set up on the main road about thirty miles apart, equipped with good horses, carriages, and boats, which was responsible for the transmission of official documents and the reception of officials and transportation of goods, forming a relatively complete postal system. In this respect, ancient Rome is the same as China. The Roman Empire built the most advanced postal delivery system known until that time except for the service in China. Its area was the whole Mediterranean world. Reliable communication from Rome to governors and military officials in far away provinces was a necessity. Rome met the need by developing the *cursus publicus* literally, "public course" a state-sponsored series of post roads with relay stations at intervals. The speed with which government dispatches and other mail could be carried about the empire was not equaled again in Europe until the 19th century. Using the relay stations, riders could cover about 170 miles (270 kilometers) in a 24-hour period. Such situation was described clearly in the book edited by Radner [22]. In the Introduction of the book [22; p.7] one can also see that: “With the expansion of the Assyrian Empire (at 670 BC), the hugely expensive relay system was extended to link all new provinces to the Assyrian heartland and each other. When the Assyrian Empire disintegrated at the end of the 7th century BC, the Royal Road system did not. Its successor state, the Neo-Babylonian Empire (612–539 BC), continued to invest in the maintenance of the infrastructure, as a number of administrative documents illustrate”. Two pictures of mail couriers can be as examples evidently. One is from ancient China at AD 220-240 [23], which is the unearthed tomb of the painting “post map” of the Wei and Jin Dynasties. Another is the mail courier in Persia [24]. It is very interested to compare the pictures of ancient mail couriers. It must be pointed out that during ancient times, only government and military officials could use the postal system, but ordinary persons could not use the system in anyway.

### **AFTER ENTERING INTO THE STAGE WITH HISTORICAL RECORDS**

Like the prehistory stage, several new information technologies have been invented and different transmission methods can be separated with the progress of substance civilization of human society.

### **The seventh is writing communication**

In the early age of Western Han Dynasty (starts from 206 BC), Chinese began to use paper [25]. We have mentioned in the above that there was last a very long time from used rope to keep records → hieroglyphics → oracle → till 770 BC, the real books were born in China. However, such kind of book was still rather heavier; the lighter paper was discovered finally after another long period of time. Such papers were made by linen fiber, which is not easy to obtain for mass production. In the Eastern Han Dynasty (25-189 AD), Cai Lun (63-121 AD) was the official residence in charge of the imperial weapons, playthings, and utensils. Cai Lun improved the papermaking process, using cheap and easy-to-get bark, broken fishing nets, rags, etc. as raw materials, greatly reducing the cost of paper production, and really invented the paper. According to expert research, at the latest in 289 AD, papermaking was passed to North Korea and Japan. During the Tang Dynasty (618-907 AD), it was passed to Arab and Southeast Asian regions. And then it spread from Arabia to Europe, Oceania, Africa, the Americas and other parts of the world, effectively promoting the development of world civilization.

### **The eighth is printing communication**

Early in the Neolithic Age, Chinese ancients have known the embossing method to prepare various decorative patterns and colors onto the surface of pottery products. They used the prepared ceramic mold with patterns and/or colors to imprint onto the surface of not yet dried pottery waiting to be baked, then the crafted pottery with patterns and colors can be produced. This is the earliest printing method in the world. The raw materials of this section were cited from the book “History of printing in China” [26].

In the Warring States Period, stamps began to appear, the words on it are chiseled irony, coated with mud printed out of the text is the main text. To the North Qi (562-564 AD), the seal should be on paper. At the end of the Eastern Han Dynasty, there was a style of lettering on wooden boards.

When did the Blocking Printing real appear in China? There were a variety of statements. After a long analysis and comparison from a lot of raw materials, in 1989 Zhang and Xiumin [26], concluded that it was at Ten years of Zhenguan (636 AD), as for appearing in the Han Dynasty, the Eastern Jin Dynasty, the Six Dynasties, the Sui Dynasty, the Five Dynasties, and the Northern Song Dynasty are all untrue. It is very interested to note that in the Tang Dynasty writer Sun Wei’s “The Collection of Sun Kezhi”, there was a record at the 851 AD of “Reading Kaiyuan (713-741 AD) Miscellaneous Newspapers”, which means that there is already a real newspaper. Therefore, the Kaiyuan Miscellaneous Newspaper was about nine hundred years earlier than the first newspaper published in Germany in 1609.

During the reign of Renzong Qingli in the Northern Song Dynasty (1041-1048), Bi Sheng, a civilian in China, invented movable type typesetting and printing, about 400 years earlier than Gutenberg, Germany, used movable type to print the Bible. Shen Kuo (1031-1095), a famous scientist at that time, clearly recorded Bi Sheng’s invention in his famous book of Mengxi Bi Tan (Vol. 18), which can be convinced without any doubt. We must say that the adoption of movable-type printing in Europe brought about the Renaissance and the rapid development of science and culture, while China lagged behind. This is a historical regret. The described invention process of printing in China: Stamps → Blocking Printing → Movable-Type Printing can be found the same writing map in the book by Carter [27]. However, Carter did not mention the embossing method to prepare various decorative patterns and colors onto the surface of pottery products in the Neolithic Age.

## The ninth is telegraph and telephone transmission

Even though human kind have used several kinds of information communications as mentioned above and you can send letters from here to there in your county, but time constraints did not have been solved yet till to the end of the eighteenth Century. At that time of period a variety of ingenious attempts to establish long lines of communicating devices were needed. This was prompted by the requirements of the military: the navy in England and the army in France. As first developed in Europe, the signaling systems adopted were mechanical structures, and significant changes in the appearance of the mechanism could be observed at a distance. So that the so-called Optical Telegraphy has been discovered. A visual system for sending information by means of two flags that are held one in each hand, using an alphabetic code based on the position of the signaler's arms. Because it was discovered first by Chappe [28], it is called the Chappe telegraph in the literature. The first practical telegraph system was inaugurated in France by Chappe in 1794; this was a semaphore or moving-arm type [29]. The idea was quickly adopted in Britain, where there were clear advantages in rapid communication with the coastal ports where the British Navy was based. After tests a shutter type was adopted, rather than a semaphore, and by the end of 1796 two telegraph lines were in operation. A shutter telegraph station had six pivoted boards, which could be swiveled by the ropes leading down to the cabin, so they were either visible or edge-on. Six shutters gives a 6-bit binary code, allowing 63 non-zero states to be transmitted. These were allocated as the 26 letters of the alphabet, ten numerals, and some useful preset sentences, such as "Defeat the French Navy immediately" [30]. However, until 1816 the Shutter telegraph was replaced by a Chappe or semaphore type, trials having convinced the authorities that this system gave better visibility.

It is not difficult to imagine that the Optical Telegraphy of Chappe or semaphore type was very useful at that time. The first is its transmission is very fast. For example, the average London-Portsmouth (the distance between the two towns is about 60 miles) message took about fifteen minutes to get there in 1796. The second is that the Chappe's telegraph network system has built in France and other European countries. In France, an entire system was working by 1794, with a line of 15 stations over a distance of 230 km. It was over this line that the first formal telegraph message was sent announcing Napoleon's capture of Le Quesnoy from the Austrians in 1794. The extent of this impressive network was completed by the middle of the 18 century, with extensions to Spain, Italy, Belgium, Switzerland and Germany. By 1852 a total of more than 4 000 km of lines were in operation, with over 550 stations in France, but by this time the electric telegraph was beginning to replace Chappe's lines, and they gradually fell out of use during the next three decades [31]. As well as France's extensive network of stations in Europe, the turn of the nineteenth century saw Chappe's semaphores widely adopted in the countries of Europe and in America. In Russia, some lengthy semaphore lines were developed linking St Petersburg, Kronstadt, Pushkin and Galchina, and one 830 km in length from St Petersburg to Warsaw. The Warsaw link was staffed by 1320 personnel and contained 220 stations. The first semaphore in the United States, again based on Chappe's system, was built by Jonathan Grout of Belchertown, Massachusetts, in 1801. It was over 100 km in length, linking Martha's Vineyard off the New England coast with Boston, and its purpose was to transmit news about shipping entering the straits. Sixteen stations were established along the route.

The stated telegraph was not using the electrical signals, which is not the real telegraph. The real electrical telegraph was discovered by S.F.B. Morse. However, before Morse's electrical telegraph, several kinds of telegraphs using such as static electricity etc. were proposed, it is necessary to be mentioned. For simplicity we just only illustrate the road map using the names of such telegraphs, which is: 1809, The von Sömmerring electrochemical telegraph [32] → 1816,

Francis Ronalds's electric telegraph<sup>1</sup> [33] → Wheatstone's single-needle telegraph [31] → 1837 Wheatstone's five-needle 'hatchment telegraph' [30].

Before discovering telegraph, Professor Morse was already a well-known painter; and there was a long story for his discovery [30]. For the Morse' discovery of telegraph, It should be noted as below. The first he thought that all of the methods as mentioned above were too complicated, and must be giving up. The second is that from the very beginning his original intention was to use the code for numbers only. The third is that he strives for help from others, for example Professor L. Gale and A. Vail. Gale was familiar with the work of the American physicist J. Henry on the efficient construction of eletromagnets. It was primarily A. Vail who, possessing the mechanical skills that Morse lacked, perfected the early instruments for the coming patent application and for public demonstrations. It is obviously that working with Gale and Vail was very helpful for Morse' discovery. As for his discovery, Morse described its principle features himself as: 1, a 'marking instrument', consisting of a pencil, pen or print-wheel; 2, use of an electromagnet to impress the instrument on a moving strip of paper; 3, a 'system of signs' (Morse code) identifying the information transmitted; 4, a 'single circuit of conductors'.

From Morse's return to the USA and beginning of creation of his telegraph in 1832, till the end of 1837, he had entered into a patent agreement with Gale and Vail for his discovery of a recording electric telegraph. Morse was inspired by the fact that the current flowing through the wire would burst into sparks when the wire suddenly stopped: if the current was cut off for a moment as a signal, the current was turned on and no spark is used as another signal, and the longer the current was turned on also as a signal. When these three signals are combined, they can represent all the 26 letters and numbers, and the text can be transmitted to the distance by electric current. In 1837, Morse finally devised the famous Morse code, which used different combinations of "dots", "strokes" and "spacing" to represent letters, numbers, punctuation and symbols. Morse and his assistants spent 4 years for their discovery. You can find the Morse' first crude telegraph instruments [34]. The first telegram in the United States was sent by Morse on 11 January 1838, across two miles (3 km) of wire at Speedwell Ironworks near Morristown, New Jersey.

In Russia, scientists also contributed to the telegraph. Pavel Shilling launched his first type of the electromagnetic telegraph in 1828 [35]. The first public demonstration of the electromagnetic telegraph took place on October 21 in 1832. The Russian emperor Nicolai I was present at this demonstration, when the first telegram consisting of 10 words was transferred over a distance of 100 meters. Pavel Shilling projected lying electromagnetic telegraph line between Peterhof and Kronshtadt. The successor of P. Shilling, Boris Jacobi, invented his first type-writing telegraph. In 1841 B. Jacobi implemented the communication line equipped with the type-writing telegraph that connected the Winter Palace with the Supreme Headquarters. In 1850 B. Jacobi designed his first printing telegraphy.

From the previous discussion, it is known that the telegram transmits symbols. To send a telegram, you must first translate the message into a code and then send it out by telegraph machine. On the receiving side, you must go through the reverse process, translate the received code into a message, and then send it to the receiver. This is not only troublesome, but also a timely two-way information exchange. Therefore, people began to explore a communication method that can directly transmit human voices. This is the "telephone" that will be discussed here. The invention of telephone can be represented by the following roadmap [36-42]:

- 1844 Innocenzo Manzetti first proposes the idea of an electric "speaking telegraph" (telephone),

- 1854 Charles Bourseul publishes the principles of a make-and-break telephone transmitter and receiver in L'Illustration, (Paris),
- 1854 Antonio Meucci demonstrates an electric voice-operated device in New York<sup>2</sup> [43-49],
- 1861 Philipp Reis constructs the first speech-transmitting telephone<sup>3</sup>,
- 1872 Elisha Gray establishes Western Electric Manufacturing Company,
- 1875 Alexander Graham Bell uses a bi-directional "gallows" telephone<sup>4</sup>,
- 1876 Elisha Gray designs a liquid transmitter for use with a telephone<sup>4</sup>,
- 1876 Tivadar Puskas invents the telephone switchboard exchange,
- 1877 Edison files for a patent on a carbon (graphite) transmitter. 1875 Thomas Edison experiments with acoustic telegraphy and builds an electro-dynamic receiver,
- 1877 Emile Berliner invents a microphone based on "loose contact" between two metal electrodes.

The facts evidently indicated that the modern telephone is the result of work of many people; it is not just the merits of one or two people, but the result that has nothing to do with anyone else.

The invention of telephone makes the communication of information of human kind another big step forward. Anyone if he/she like can talk with anybody freely at anyplace in the world if there equipped with telephone wires and post office. However, during the process of inventng the telephone, there were too many additional stories appeared, here simply mentioned in Remarks 2, 3 and 4 stories for which most of the people have not wanted to happen because they are not what people want.

### **The tenth is vacuum tube and transistor**

Vacuum tube is an electronic vacuum element that can be used for controlling the flow of electrons through the emitted electrons by applied potential within a sealed glass or metal container. Usually, one only mentions the invention of diode in 1905 by J.A. Fleming [50] and triode in 1907 by L. De Forest [51]. In fact, some works before their must be mentioned because they were the basis and guide for the works of Fleming and De Forest, which just like the invention of telephone. For example, in 1857 Heinrich Geissler [52, 53] studied low-pressure gas filled tubes, which ultimately led to fluorescent lamps. Johann Wilhelm Hittorf in 1869 [54] also studied similar gas discharges. Eugen Goldstein in 1876 called these the "cathode rays", and was interpreted as moving charged particles in 1879 by William Crookes [55]. Joseph John Thomson discovered the electron during 1897-1899 [56]. In addition [57], vacuum arc deposition (VAD) was first investigated at the end of the 19th century by A.W. Wright and T.A. Edison, as mirror coatings and seed layers for phonogram replication molds, respectively. The VAD research was also helpful for the invention for vacuum tube. The invention and application of the vacuum tubes caused the information communications for human kind a big step forward, especially during the decades from World War I to World War II, basically adapted and met the needs of radio communications and intelligence.

However, even during in the World War II, people felt eagerly that the heavy and backward vacuum tubes and electromechanical switches should be replaced by solid devices because a standard radiotelephone at the time, almost 40 % of its weight and half of its volume came from bulky vacuum tubes and dry batteries [58]. In addition, the quantum theory of solids was fairly well established by the mid-1930s, when semiconductors began to be of interest to industrial scientists seeking solid-state alternatives to vacuum-tube amplifiers and electromechanical relays. So, early in 1938 Mervin Kelly in Bell Labs set up a research group, and the program of the group was basic research on solid-state physics. World War II forced them to stop. At the end of the war, Kelly [59] (who was Bell Labs Executive Vice

President, initiated in 1945) immediately reopened the research team and invited Schockley, Bardeen and Brattia to join the group. After several years of hard research, they finally created the world's first solid-state transistor in 1947, and the three persons won the Nobel Award in 1956 [60]. The invention of transistors has undoubtedly brought human information communication to a higher level, faster and more efficient. It also promotes the advancement of science and technology and industry to a certain extent. However, the title "The birth of the information age" used by Riordan and Hoddeson's book<sup>5</sup> [61] is obviously inappropriate. There is no special argument for it in the book on the one hand, and it is exactly the opposite of the subject of another article [62] on the other hand. This article argues and confirms that there is no information age in the whole developmental stages of the substance civilization in human society.

### **The eleventh is computer network transmission**

After the invention of vacuum tube, the inform communication of human kind has input into the stage of wireless communication. Radio station communication cannot be lack of electronic tubes. The subsequently computer communication network cannot be lack of computers. So, the invention of electronic computers is a key issue. 1946, John W. Mauchly and J. Presper Eckert at the University of Pennsylvania developed the ENIAC I (Electrical Numerical Integrator and Calculator) [63]. The ENIAC contained 17 468 vacuum tubes, along with 70 000 resistors, 10 000 capacitors, 1500 relays, 6 000 manual switches and 5 million soldered joints. It covered 167 m<sup>2</sup> of floor space, weighed 30 t, and consumed 160 kW of electrical power. In one second, the ENIAC could perform 5 000 additions, 357 multiplications or 38 divisions. The use of vacuum tubes instead of switches and relays created the increase in speed, but it was not a quick machine to re-program. Programming changes would take the technicians' weeks, and the machine always required long hours of maintenance. It took the team two years and \$ 750 000 to build it. However, John Atanasoff and Clifford Berry of Iowa State University worked from 1935 to 1939 on the Atanasoff-Berry computer (the automatic electronic digital computer) [64]. In 1939, they built the first electronic digital computer, named ABC computer. Atanasoff said that "I later called the Atanasoff Berry Computer (ABC), to honor the memory of Berry's extraordinary competence" [64]. The final computer was the size of a desk, weighed 700 pounds, had over 300 vacuum tubes, and contained a mile of wire. It could calculate about one operation every second. There is also a stories about the computer, but not the ones people want to hear<sup>6</sup>.

The Atanasoff Berry Computer, later named the ABC, was built at Iowa State University from 1939-1942 by physics professor J.V. Atanasoff and his graduate student, Clifford Berry. The Atanasoff-Berry ABC Computer is in the Department of Computer Science at the Iowa State University, <http://jva.cs.iastate.edu/operation.php>.

It must to point out that Atanasoff and Berry did not apply for a patent for the computer because Atanasoff was moved to a new place, although in August 1940 he wrote a comprehensive manuscript which fully described the principles of his machine, including detail design features. After Atanasoff and Berry learned that Mauchly and Eckert were granted a patent on ENIAC, they filed a lawsuit in court to defend their original right to invent the computer. After near 30 years of public lawsuit, it was finally solved in 1973. Atanasoff was declared by the U.S. Supreme Court to be the true inventor of the electronic computer.

After invented the transistor in 1947, the first fully transistorized computer was appeared in 1954 successively. The period time from transistor to transistor computer is shorter than one from vacuum tube to computer equipped by electric tubes, the reasons result from that the experience of manufactured the vacuum tube computer. The real first fully transistorized computer was invented by the Felker Group at Bell Lab in 1954 [65]. They manufactured the

Tradic (Transistor Digital Computer) from 1951. In the Tradic Ge point-contact diodes were used for logic operations and other circuit functions, and point contact transistors were used in circuits to reshape pulses distorted by the logic networks. 684 transistors and 10 358 Ge point-contact diodes were used. Word size is 16 bits-serial. Number storage is 16 addressable electrical delay lines. Addition or subtraction time is 16 microseconds. Multiplication or division time is less than 300 microseconds. Digital-to-analog converters are two that converted numbers to voltages. Clock: 30 W at 1 megacycle supplied by an electron tube because no transistors were available which could supply this much power at this frequency.

The first practical ICs (Integrated circuit) were invented by Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor [59]. By 1961, the first integrated circuit (IC) computer made by Texas Instruments with 587 integrated circuits, this integrated circuit computer is only one-half the size of the latter compared to a computer made with 8 500 transistors of the same function, and weighs only 1/150 of the latter.

It is obviously that the size of computers is greatly reduced as the used electronic elements from vacuum tubes to transistors to IC.

### **The twelfth is mobile communication**

After the invention of telegraph and telephone, people are thinking that telegrams and telephones cannot talk to anybody anytime, anywhere, although people with the right equipment can communicate anywhere. Is it possible that everybody can have a phone to use it freely? This is the motive of the invention of mobile phones.

Nathan Stubblefield in 1902 invented wireless telephone first in the world [66]. In 1908, he was granted the US patent 887 357, the title of the patent being the Wireless Telephone. The patent states that “The present invention relates to means for electrically transmitting signals from one point to another without the use of connecting wires, and more particularly comprehending means for securing telephonic communication between moving vehicles and way stations. ... The principle object of the invention is to provide simple and practical means of a novel nature whereby clear and audible communication can be established, said means being simple and of a character that will permit certain of the station mechanisms to be small and compact”. However, Stubblefield made no headway in commercializing his latest invention. In addition, Stubblefield himself made no further progress beyond his previous work.

After then, others also reported their inventions of mobile phones. For example, Bell Labs in 1938 made the world’s first “mobile phone” for the US military, some engineers from Motorola took part in the work. During World War II Motorola Corporation had manufactured a series of (Walkie Talkie) SCR for the US military, contributing to the victory of World War II. But such Walkie Talkies are very heavy, for example, SCR300 is a tunable high frequency FM communication device, with 16 kg weight and the effective distance of communication of around 16 km. (Handy Talkie) SCR-536 which was made in 1942 weighs 4 kg and its range of communication is 1,5 km in the open space but only 300 m in the woods. On March 1, 1948 the first fully automatic radiotelephone service manufactured by Bell Labs began operating in Richmond, Indiana, eliminating the operator to place most calls [67].

In 1973, the well-known real mobile phone was made by Martin Cooper at Motorola. On October 17, 1973, Motorola filed a patent for its own cellular radio system; and the US patent 3 906 166 was granted to Cooper et al. on Sept. 16, 1975 [68]. The patent states that “This invention relates generally to communications systems, and more particularly to organized radio telephone systems having a plurality of base station and portable units, each having a predetermined coverage area, and means for adjusting the operating frequencies of the portable units to provide the optimum communications path”. What Cooper’s team invented

was the first handheld cell phone. But not the cell phone itself. That had already been done on the Metroliner train. Motorola's successful field work caused the American magazine Popular Science to picture the portable phone on their cover in July, 1973.

However the mobile phone DynaTAC invented by Cooper was still too heavy, weighing around 2 pounds. It needed 10 hours for charging, only for half an hour of talk. The price of the phone was as high as \$ 3 995 for one set. The Motorola DynaTAC is the prototype of the first hand-held cellular telephone, which was the first public call ever made on a cellphone by Martin Cooper on April 3, 1973, and it is real like a heavy brick. From the Washington Post in September 9, 2014 [69], one can find the picture of Cooper holding that brick.

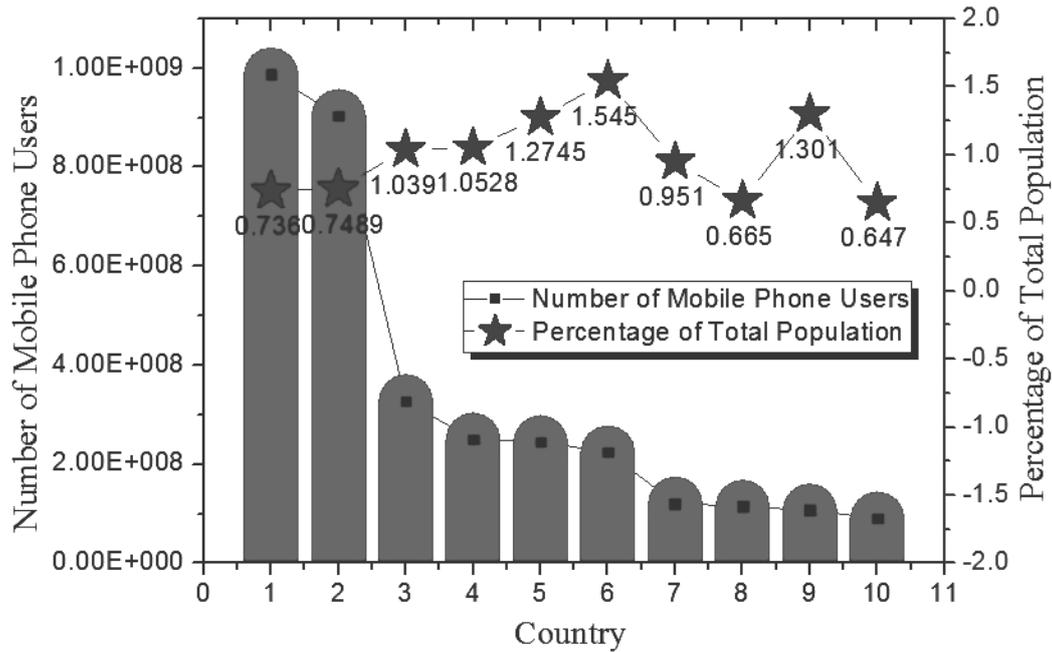
More than ten years later when someone visited Cooper, he talked about the phone very interesting [70]. He said: "People thought I was crazy to think that cellular, mobile phones you could carry around in your hand would be successful". Now, the idea of cellular phones seems trivial, obvious. But Cooper does not like to dwell on the past: "For me this is exciting – being here right now, this year. It's just amazing the difference between now and four years ago, when it was really pretty boring." Cooper also mentioned that "My idea was that it wasn't natural for people to stand around talking to a big box fixed to a wall. So why shouldn't you be able to use a data communications device that you can take anywhere you want to go?" Like a philosopher, Cooper may be self-effacing, but he is confident: "It is fun being part of history; what better thing can you do in your life than try to change the world?"

Early cell phones were just for talking. Gradually, features like voicemail were added, but the main purpose was talk. Eventually, cell phone manufacturers began to realize that they could integrate other technologies into their phone and expand its features. The earliest smartphones let users access email, and use the phone as a fax machine, pager, and address book. The purpose of the cell phone has shifted from a verbal communication tool to a multimedia tool, often adopting the name "mobile device" rather than being called a phone at all. We now use our cell phones more for surfing the web, checking email, snapping photos, and updating our social media status than actually placing calls. The cell phones of today are also replacing our other gadgets, such as cameras and video cameras. Right now, 5G mobile phone will be appeared soon. For the past four generation of mobile phones 1G-4G, not only their appearance, especially their functions and applications are much advanced, one generation is better than one generation. Today the mobile phone: Its evolution from a communication device to a universal companion. Therefore, most of the people in the world everyone has a cell phone.

As the progress of materials civilization of human society Mobile Phone users in the world constantly increased in the world, reaching to an astonishing degree. Presently about 5,6 billion people uses Mobile phones out of the total world population of about 7,012 billion people. So, almost 80 %, of people in the whole world has a cell phone. Figure 1 [71] shows top 10 Countries by number of highest mobile phone users and percentage of their total population.

### **The thirteen is internet communication**

After invented computer, people must consider the issue of computer network, in order to improve and enhance greatly its role and capabilities compared to single computer in information communications, control, storage and etc. In fact, during the 1950s and 1960s, there were various computer networks in the word, but they were independent of each other and have no connection. This is so-called the first generation of computer networks, which is a single host computer-centric remote connection system. For example, in the 1950s, the U.S. military radar system Semi-Automatic Ground Environment (SAGE) was the early networks of computers included [72]. Another one is the aircraft booking system consisting of a computer



1. China, 2. India, 3. United States, 4. Indonesia, 5. Brazil, 6. Russia, 7. Japan, 8. Pakistan, 9. Germany, 10. Nigeria

**Figure 1.** Top 10 countries by number of highest mobile phone users and percentage of total population, the data were taken from [71].

computer and more than 2 000 terminals across the United States in 1950s. The terminal is a computer's external device including display and keyboard, no CPU and memory. In such computer network, because all terminals share host resources, the terminal and the host each occupy a separate line, making the low utilization of lines. The host is responsible for communication and data processing, so the host is inefficient. In addition, this kind of network organization is a form of centralized control, so the reliability is low. Once the host has a problem, all terminals must be forced to stop working. In a word, such network is not the real computer network what people want.

Except such demand for the development of computer network, other reasons from two sides promote it progress as well<sup>7</sup> [73-76].

However, the Internet was originally a brainchild of as strategic study in the cold war years, but the key problem is that how USA authorities could communicate and command centers could function after a nuclear strike. Therefore answer must be that a special command-and-control network was needed. This network would be perceived in any traditional wisdom to be unreliable at all times because it was not centrally commanded. It would be designed from the get-go to transcend its own unreliability. All the nodes in the network would be equal in status to all other nodes, each node with its own authority to originate, pass, and receive messages. Nodes can also be easily added on or removed without disturbing the function of the network. Such a network would serve as the primary purpose of a working network in the event of local malfunctions.

With ideological and theoretical guidance, with political and military urgent needs, and with the deployment of the highest level of the country and the generous financial and material support, coupled with the hard work of a lot of bright people<sup>8</sup> [76-78], the real computer network has no reason to be unsuccessful. In fact, the first four nodes of the ARPANET (ARPA stands for Advanced Research Project Agency) were connected using 50 kbit/s

circuits between the University of California at Los Angeles, the Stanford Research Institute, the University of California at Santa Barbara, and the University of Utah in 1969. This real computer network was created by the commission of the US Department of Defense.

One can see evidently that the advent of the internet was not accidental.

After a lot of hard work by many professionals and non-professionals during many years, the internet, from the prototype of the four-node host computer at that time, has made a great strides forward, and has become a convenient World Wide Web for everyone in all countries of the world.

The today's internet includes educational, scientific, commercial, governmental, and other networks, all of which use the same set TCP/IP of communications protocols, consists primarily of the collection of billions of interconnected WebPages, and allows almost all computers worldwide to connect and exchange information. From the simple type internet consisted of four hosts in 1969 to present highly developed internet, there are many things needing to be described. Because it is not the main aim of this article, only two segments are pointed out briefly in the Remarks 9 and 10.

Figure 2 shows top 10 countries by number of all internet users and percentage of total population [77]. It is clear that for these top countries, internet user numbers are all over 50 % of their population, two of them are over 90 %. As for the whole world, internet user numbers are 4 021 billion, or 53 % of the world's population [78].

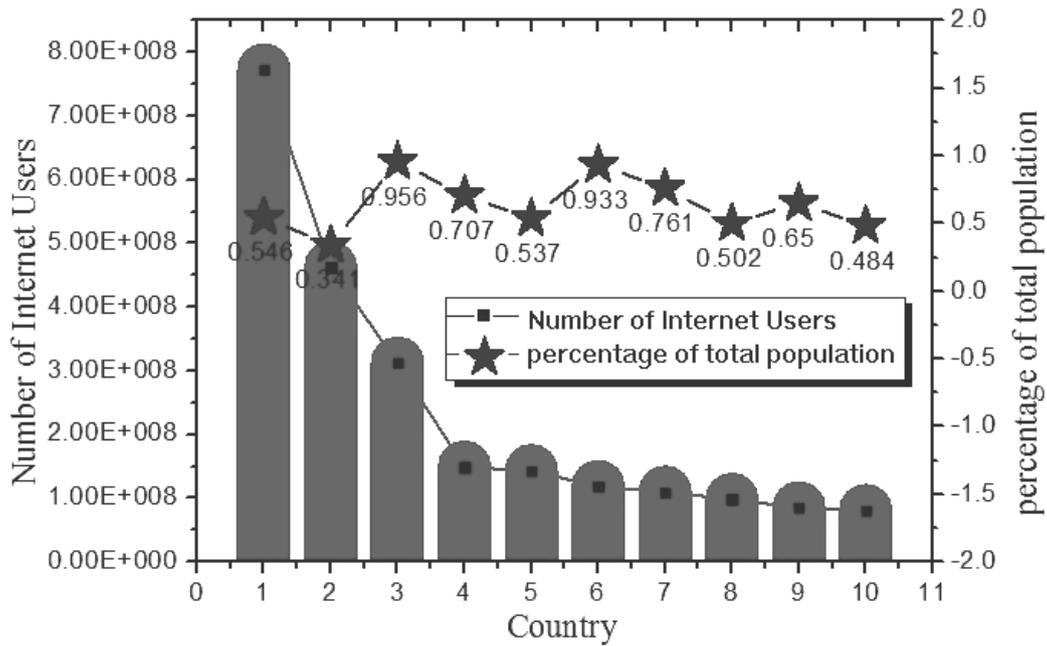
Figure 3 shows growth of internet hosts from 1969 to December 2017 [79]. The number of internet hosts was only 4 in 1969, but over 1 billion till December, 2017, the growth rate is near  $10^{10}$ . The internet has changed much in the past years since it came into existence. The internet will be definitely changed a lot in future. The obvious example is the Internet of Things.

There is an important issue should be pointed out finally though we just describe it very simple. The point is that the emergence of internet also carried some negative effects. For example, the network is crowded, the advertisements on the webpage suddenly appear, the actual network speed is much lower than the indicated speed, hackers, especially network harassment and cybercrime, etc. These are making the network users, especially those who are basically inseparable from the network search and other people suffering. Of course, these serious problems are not all caused by the internet itself, but mainly by management problems and social boredom. This may be why Jakobsson wrote a 386-page book of "The Death of the Internet" [80].

### **Solid historical facts can explain the problems**

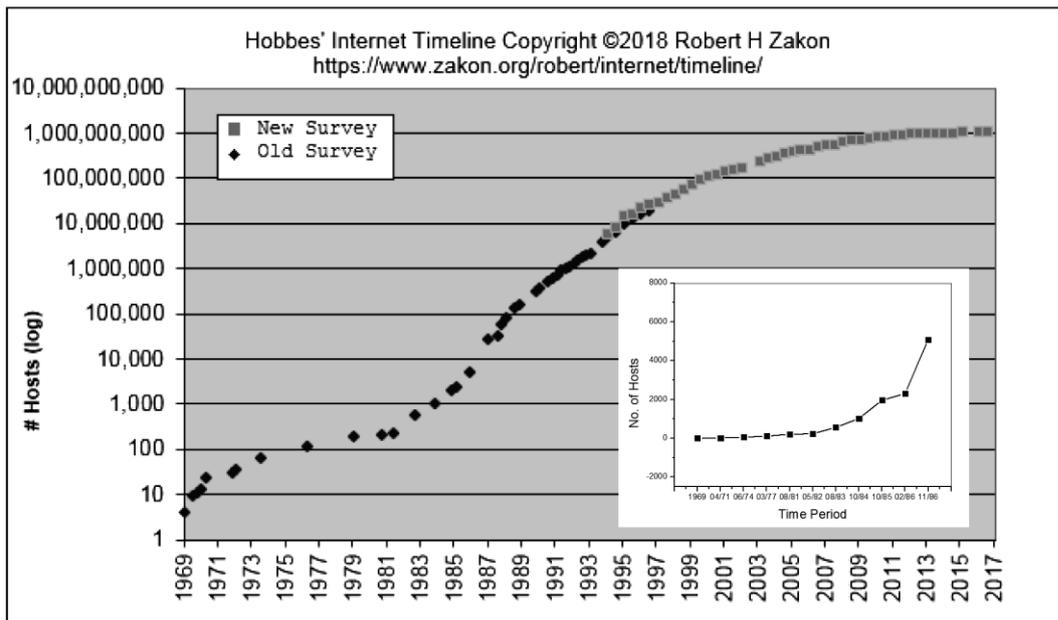
The exchange of information and communication between humans from the initial era of the past, until today's highly developed internet communication, in accordance with the development of the civilization, was divided into 13 stages (of which 6 were prehistoric and 7 were historical recorded) for discussion. Though such description and discussion were not very detailed, they were quite comprehensive. What can these solid historical facts of information tell us?

- 1) All historical facts show that from the very beginning of human beings, information and its communication and dissemination have emerged. These always accompanied human beings, never left, never interrupted.
- 2) Along with the development of human material civilization, information and its transmission are also accompanied by development from low level to advanced level.
- 3) In the course of development, when human beings feel that information and its transmission are not very compatible, there must be some people, intentionally or unintentionally, individually or in small organizations to develop information and its



1. China, 2. India, 3. United States, 4. Brazil, 5. Indonesia, 6. Japan, 7. Russia, 8. Nigeria, 9. Mexico, 10. Bangladesh

**Figure 2.** Top 10 countries by number of all internet users and percentage of total population, the data were cited from [77].



**Figure 3.** Growth of internet hosts from 1969 to December 2017 [79]. The inset shows the detail growth of internet host from 1969 to November 1986.

transmission mode, and make it adapt again. Such a period of time is uncertain, but human society has not had any historically recorded chaos.

- 4) Information and its exchange and dissemination are necessary conditions for human beings to emerge, survive and develop. Humanity has survived for several million years, with a history of civilization of 5-6 thousand years. Without the exchange and dissemination of information, people are absolutely an isolated individual. Human beings cannot be produced, and it is impossible to survive and develop. Information and its communication

and dissemination are as necessary as air and water to human beings, and cannot be left without it any moment. Each kind of animal in the animal kingdom has its own information exchange and dissemination, otherwise it will be destroyed. The animal world is still the same, not to mention the highly developed human beings, who can make themselves without any information exchange and dissemination, and become individuals who are absolutely isolated?

- 5) All we described the historical facts that about the whole information and its communication and dissemination for the emergence and development of mankind, completely refutes all at once the notion or theory that the occurrence of information age (or information society) results from the advent of computers or the internet or any other invention. As long as we still respect the history, but also face the facts, it is pale and powerless to say that the invention of certain artifacts has led to the emergence of the information society. Information and its dissemination have followed mankind from the very beginning, never leaving, but only gradually evolving from the lower to the higher.

Then why was it proposed that after the invention of computers or the Internet, human society has entered into an information age. That was shouted loudly in the world, and there are still many authors following that? Let us try to analyze it in a simple way.

The first is that they themselves are not studying and looking for the entire history of information that is closely following human development and its spread. Even if they read the historical descriptions from others, they have to think them carefully. This argument is particularly clear when comparing the contents and conclusions of two books. One is “The Information Age: Economy, Society and Culture” by Castells [81], and the other is “The Information: A History, A Theory, A Flood” by Gleick [1]. The former basically does not involve the occurrence and development of information technology that has been followed by human society as described above, indicating that the author does not care about the history of the development of information, so the title of the book is marked obviously as “The Information Age”<sup>11</sup> [82, 83]. The latter basically writes about the history of the development of information, even the terms “information society” and “information age” are hard to see in the book. In addition, Gleick [1] also wrote that “The alphabet was a founding technology of information. The telephone, the fax machine, the calculator, and, ultimately, the computer are only the latest innovations devised for saving, manipulating, and communicating knowledge. ... We know about streaming information, parsing it, sorting it, matching it, and filtering it. ... so we see information in the foreground. But it has always been there. It pervaded our ancestors’ world, too, taking forms from solid to ethereal, granite gravestones and the whispers of courtiers. The punched card, the cash register, the nineteenth-century Difference Engine, the wires of telegraphy all played their parts in weaving the spider web of information to which we cling. Each new information technology, in its own time, set off blooms in storage and transmission. From the printing press came new species of information organizers: dictionaries, cyclopaedias, almanacs – compendiums of words, classifiers of facts, trees of knowledge. Hardly any information technology goes obsolete. Each new one throws its predecessors into relief”. The meaning of this rather longer paragraph by Gleick indicates obviously in agreement with our opinions analyzed above: information always exists since the very beginning in human kind, every information technology either the old The Beacon Tower or the newest and advanced internet is the same from the nature, no difference, thus claiming that “human beings have entered the information age” violated all historical facts, and is without a basis hence untenable.

The second is that the age and society are big words, which should be a long period of human society. Only by carefully studying and analyzing the whole process of substance civilization

of the whole human society and having its own theoretical description (of course, it is not impossible to analyze it by the theory proposed by others), one can be able more accurately to name all or one of them. Otherwise, it will be difficult to avoid blindness or following the statements of others. Most of the authors who put forward this kind of “information age” in their articles or books may have problems in this respect.

The third is that because many articles and books are talking about the information age, so some people may follow the trend which cannot be ruled out.

The last point is that the vicious speculation of the media. After the computer and the network were successively invented, the media, under the excessive noise of some people in the industry, has spared no effort to hype viciously. It seems that except these newly invented information technologies, human beings have never had any other information tools. Human society seems that never have lived an appropriate information life and service. This of course is totally different from the fact that so many information technologies and means we discussed above. Such kind type of media hype has actually been opposed and criticized before. Early in the 17th century, Thomas Hobbs resisted the new media hype of his time. He said in his book [84] “The invention of printing, though ingenious, compared with the invention of letters, is no great matter”. Gleick [1] cited the words of Hobbes also, indicating that he agrees with this point of view.

## CONCLUSIONS

For the nature of information too many papers and books have discussed this problem. Though “there is still not an agreed and explicit conceptualization or definition of information” [3] in the world, and according to the statistics [4], there are more than 200 information definitions available in the literature, however, the common points of view from the mainstream academic community of information sciences do not believe that information is a matter. Of course, though information is not a matter but it relates with matter, just as said in our definition of information that information is not a substance but needs to have a physical carrier. The nature of information is too complicate so there is still no common understanding and conclusion up today.

Comprehensive history of information development for human society has been discussed and analyzed in the paper though every item is not so detail. According to the all historical facts from the very beginning of human beings the conclusion is evidently that information and its communication and dissemination have emerged with occurrence of human beings, always accompanied by human beings, never left, and never interrupted. The notion or theory that the occurrence of information age (or information society) results from the advent of computers or the internet or any other invention is opposite to the whole history facts for the human society.

Just because many people do not care the whole history of information, making them easy to convince that there is an information age in the whole developmental stages of the substance civilization in human society. But they are misunderstanding. The reasons have analyzed from the whole history of information.

## REMARKS

<sup>1</sup>B.F. Ronalds wrote in 2016 [33] that Francis Ronalds was her great-great-great-uncle, and she published his biography.

<sup>2</sup>Antonio Meucci (1808-1889) had already created the first model of a telephone in Italy in 1834, tested electric transmission of the human voice in Havana, Cuba in 1849 and

demonstrated his electric telephone in New York, USA in 1850. However Meucci fell into a tough period, not being able any more to pay the \$ 10 annual fee for funding for a true patent of telephone in 1874, so that eventually he did not get the patent. In 1875, Bell successfully applied for the invention of the telephone patent. For that, Meucci was very angry. He repeatedly raised objections and protests to the U.S. government. Finally, in 2002, 113 years after Meucci's death, the U.S. Senate and the House of Representatives passed a resolution in front of the iron certificate, declaring Meucci is the true father of the phone. The last two paragraphs of the U.S. Congress bill (H. Res. 269 – 107th Congress (2001-2002)) states that: "Whereas if Meucci had been able to pay the \$ 10 fee to maintain the caveat after 1874, no patent could have been issued to Bell: Now, therefore, be it; Resolved, That it is the sense of the House of Representatives that the life and achievements of Antonio Meucci should be recognized, and his work in the invention of the telephone should be acknowledged". Recently many authors reported such contents in details, e.g. [43-49]. That is to say that history finally completely vetoed Bell's invention of the telephone and maintained Meucci's pioneering position in the invention of the telephone.

<sup>3</sup>The facts shows that German scientist J.P. Reis is seen as a leading telephone pioneer. The Reis telephone was being developed from 1857 onwards. Allegedly, the transmitter was difficult to operate, since the relative position of the needle and the contact were critical to the device's operation. Thus, it can be called a "telephone", since it did transmit voice sounds electrically over distance, but was hardly a commercially practical telephone in the modern sense. Thomas Edison tested the Reis equipment and found that "single words, uttered as in reading, speaking and the like, were perceptible indistinctly, notwithstanding here also the inflections of the voice, the modulations of interrogation, wonder, command, etc., attained distinct expression".

<sup>4</sup>Gray and Bell submitted the patent application for the invention of telephone on the same day (February 14, 1876). As a result, although both were granted, one was patent and the other was patent caveat. For more than a century since then, there has been a constant dispute between the two sides. Bystanders have not had unified opinions on this, but it seems that there are more people who prefer the Gray. In particular, when people thought of the patent examiner charging Bell's \$ 100 at that time, the negative words even the word "stealing" for Bell appeared. Because it is only related to this article, we cannot spend more discourse on it.

<sup>5</sup>In their book "Crystal Fire: The Birth of the Information Age", M. Riordan, and L. Hoddeson [65] describe the invention of transistor in great detail, which is worth to read.

<sup>6</sup>Atanasoff in 1947 published a long (54 pages) paper [64], in which he presented in more details his interest in computing, the constructed process of ABC computer and the subsequent litigations and controversies. Regarding the litigations and controversies, Judge Larson signed his decision on October 19, 1973. The decision comprised 248 pages of legal-cap paper, with an appendix of more than 60 pages. Here, just few passages are cited:

"The Court has heard the testimony at trial of both Atanasoff and Mauchly, and finds the testimony of Atanasoff with respect to the knowledge and information derived by Mauchly to be credible".

"Between 1937 and 1942, Atanasoff, then a professor of physics and mathematics at Iowa State College, Ames, Iowa, developed and built an automatic electronic digital computer for solving large systems of simultaneous linear algebraic equations".

"Eckert and Mauchly did not themselves first invent the automatic electronic digital computer, but instead derived that subject matter from one Dr. John Vincent Atanasoff".

"I find and conclude that the ENIAC [patent] is invalid and unenforceable".

<sup>7</sup>These two sides of reasons are from thought and theory, and Politics and military. J.C.R. Licklider in 1960 published a paper “Man-Computer Symbiosis”, developing the idea of a universal network [73]. He proposed that interactive computers could provide more than a library function, and could provide great value as automated assistants. He described a computer assistant that could answer questions, perform simulation modeling, graphically display results, and extrapolate solutions for new situations from past experience. Licklider foresaw a close symbiotic relationship between computer and human, including sophisticated computerized interfaces with the brain. In 1962, Licklider and Clark published another paper “On-Line Man-Computer Communication”, in the paper they presented the visionary ideas for a Galactic Network [74]. Later on Licklider sent a memorandum about Information Processing Techniques Office (IPTO). He became the first head of IPTO in October 1962. He and colleagues discussed the concept of the “Intergalactic Computer Network”, a computer network intended to allow general communications among computer users.

Another was from the event that the launching of the Soviet Union’s Sputnik, the first man-made object to orbit our planet during in the Cold War. It occurred on October 4, 1957. This case caught the United States by surprise and generated an awareness that we had fallen badly behind in science and technology. In response to this, in February 1958, President Eisenhower created the Advanced Research Projects Agency (ARPA), designed to promote research that would ensure that the Communists would never again beat America in any technological race [75].

One of ARPA’s offices was the Information Processing Techniques Office (IPTO), which funded research in computer science and was highly successful in its early days, making great strides in the areas of time sharing, networking (spawning the Internet), packet satellite networking, packet radio networking, artificial intelligence, digital signal processing, high performance computing, hypertext, and much more. Licklider was the first head of IPTO in October 1962. He worked extremely hard to make his contribution to the advancement of the first real computer network, even though he left the IPTO in 1965 and returned to MIT to teach.

<sup>8</sup>As for the hard work of a lot of bright people, we just explain it using the following examples [75, 76]. In 1964, researchers at Dartmouth College developed the Dartmouth Time Sharing System for distributed users of large computer systems. Also in 1964, a research group at Massachusetts Institute of Technology supported by General Electric and Bell Labs used a computer to route and manage telephone connections. Throughout the 1960s, Paul Baran, and Donald Davies independently developed the concept of packet switching to transfer information between computers over a network. Davies pioneered the implementation of the concept with the NPL network, a local area network at the National Physical Laboratory (United Kingdom) using a line speed of 768 kbit/s. In 1965, Western Electric introduced the first widely used telephone switch that implemented true computer control. In 1966, Thomas Marill and Lawrence G. Roberts published a paper on an experimental wide area network (WAN) for computer time sharing.

<sup>9</sup>One of the two points is that on October 24, 1995, the Federal Networking Council (FNC) unanimously passed a defining the term internet. This definition was developed in consultation with members of the internet and intellectual property rights communities. RESOLUTION: The FNC agrees that the following language reflects our definition of the term “Internet”. “Internet” refers to the global information system that (i) is logically linked together by a globally unique address space based on the Internet Protocol (IP) or its subsequent extensions/follow-ons; (ii) is able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) suite or its subsequent.

Another point is that in the 1970s, computer scientists named Vinton Cerf and Bob Kahn had begun to solve the problem by developing a way for all of the computers on all of the world's mini networks to communicate with one another. They called their invention "Transmission Control Protocol," or TCP (later, they added an additional protocol, known as "Internet Protocol". The acronym we use to refer to these nowadays is TCP/IP)<sup>10</sup> [86]. In 2004, they won the Turing Award, the highest award in the computer science community. This is the first time that the Turing Award has given scientists who have made outstanding contributions to the creation of the internet.

<sup>10</sup>Cerf, V.G. and Kahn R.E.: *A Protocol for Packet Network Intercommunication*. Transactions of Communications COM **22**(5), 627-641, 1974.

<sup>11</sup>Such situation is also appeared in the Chinese book in describing the issue of information. Two books are just cited as examples. They all firmly believe in and promote the "information age" and "information society". One is Zhong Yixin's book "The Principles of Information Science" [82]. It claims that "human beings have entered the information age", "the entire era is called the 'information age', and the entire society has also evolved toward the "information society". The other is the "World Map of the Information Age" written by Wang Xiaodong [83], which is also the content of the information age and the information society. Neither of the two books deals with the history of the emergence and development of information in human society, and therefore all of their claims that human society has entered the "information age" have become castles in the air, without any supports by the historical facts.

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# TOWARDS AGENT-BASED MODEL SPECIFICATION OF SMART GRID: A COGNITIVE AGENT-BASED COMPUTING APPROACH

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## ABSTRACT

A smart grid can be considered as a complex network where each node represents a generation unit or a consumer, whereas links can be used to represent transmission lines. One way to study complex systems is by using the agent-based modeling paradigm. The agent-based modeling is a way of representing a complex system of autonomous agents interacting with each other. Previously, a number of studies have been presented in the smart grid domain making use of the agent-based modeling paradigm. However, to the best of our knowledge, none of these studies have focused on the specification aspect of the model. The model specification is important not only for understanding but also for replication of the model. To fill this gap, this study focuses on specification methods for smart grid modeling. We adopt two specification methods named as Overview, design concept, and details and Descriptive agent-based modeling. By using specification methods, we provide tutorials and guidelines for model developing of smart grid starting from conceptual modeling to validated agent-based model through simulation. The specification study is exemplified through a case study from the smart grid domain. In the case study, we consider a large set of network, in which different consumers and power generation units are connected with each other through different configuration. In such a network, communication takes place between consumers and generating units for energy transmission and data routing. We demonstrate how to effectively model a complex system such as a smart grid using specification methods. We analyze these two specification approaches qualitatively as well as quantitatively. Extensive experiments demonstrate that Descriptive agent-based modeling is a more useful approach as compared with Overview, design concept, and details method for modeling as well as for replication of models for the smart grid.

## KEY WORDS

agent-based modeling, cognitive agent-based computing, complex networks, smart grid

## CLASSIFICATION

JEL: C65

## **INTRODUCTION**

A smart grid focuses on the complex interactions between utility service providers and consumers. It involves the non-linear dialogue of power and information data between utility service providers and consumers [1]. The complex interaction in the form of repeated auction, fluctuating supply and demand add complexity to the nature of a smart grid. Because of this complex nature, a smart grid can be considered a complex system.

The study and understanding of any complex system are associated with the modeling of the system. Modeling complex system allows better understanding and analyzing the emergent behavior of each entity involved in the system [2]. Being a complex system, a smart can also essentially be modeled in the form of either agent-based or complex network-based models [3, 4]. These models can well represent the smart grid in term of its various components, their behavior, and communication among them for energy distribution and management.

A particular way of modeling a smart grid as a complex network is by including its various components such as generating units, consumers, distributors, and other components as nodes and communication lines as edges. Chassin et al. in [5] developed the complex network model for the US power grid by considering nodes as power sources and consumers, while edges as communication lines. After developing different complex networks, we are able to use the mathematical tool for computing centrality measures and some metrics on such networks. These measurements allow studying the global behavior of each component in a large-scale power system network.

In scientific literature, agent-based modeling (ABM) and the multi-agent systems (MAS) are successfully used in the smart grid domain. Some of these works have been discussed in the later section of the article (see discussion section). However, these works lack in any ABM specification approach for documenting ABM. An ABM specification is most important for understanding as well as replication ABM. The lack of specification methods causes issues such as low understandability of the model, impossibility to replicate and extend the model, and impossibility to integrate with the existing system. So there is a need for an easily understandable methodology to describe and document an ABM, specifically in the smart grid domain.

This study is motivated by the lack of specification studies in the domain of smart grid. To this end, this article presents a first step towards the use of specification methodology for the ABM development, in particular for the smart grid system. We adopt two approaches. The first method is ODD (short for Overview, Design concept, and Details) [6] and the second is DREAM (short for Descriptive Agent-based modeling) [3]. The proposed study supports ABM developing by using specification methods starting from conceptual modeling to validated ABM through simulation. It also supports modeling complex system, more effective knowledge transfer, and communication between multidisciplinary researchers. To validate our work, we consider a case study from the smart grid domain. In the case study, we consider a large set of the network in which different consumers and power generation units are connected with each other through different configuration. In such a network, communication takes place between consumers and generating units for energy transmission and data routing. We demonstrate how to effectively model a complex system such as a smart grid using specification methods. Finally, we present a comparative analysis of both specification techniques.

Our main contributions can be listed as follows:

- 1) A proposed approach for modeling and simulation of the smart grid using the complex network and agent-based modeling approaches.

- 2) The ODD specification approach used for ABM model of smart grid.
- 3) The DREAM specification approach used for ABM model of smart grid.
- 4) A comparative analysis of ODD and DREAM specification techniques.

The rest of the article is structured as follows: Section 2 presents basic background and concepts, in Section 3 a model development is presented, Section 4 is dedicated for results and discussions, the article ends with conclusions formulated in Section 5.

## **BACKGROUND**

In this section, we present the basic concept and understanding of cognitive agent-based computing approach, DREAM, and ODD specification approaches.

### **COGNITIVE AGENT-BASED COMPUTING APPROACH**

Niazi and Hussain in [7] have presented a unified framework called cognitive agent-based computing framework. The framework is designed for facilitating the development, comparison, communication, and validation of models across different scientific domains. Here, the word Cognitive is used because the goal of the framework is to develop cognition or understanding of the different aspects of the model or system under study. The framework offers tutorials and guidelines in the form of four different modeling levels. This approach involves the process of taking any complex system from the real world and converting it into a suitable simple model by using specific modeling level such as exploratory or descriptive agent-based approach. The exploratory approach involves the use of agents to explore the complex systems, identify which agent-based model is feasible for the specific problem then develops the proof-of-concept and also explains what kind of data is required for validation and verification of the model. The descriptive agent-based modeling level is the process of presenting ABM in the form pseudocode, a complex network of the model, social network analysis. The framework combines other modeling levels named complex network modeling and validation/verification modeling.

### **DESCRIPTIVE AGENT-BASED MODELING**

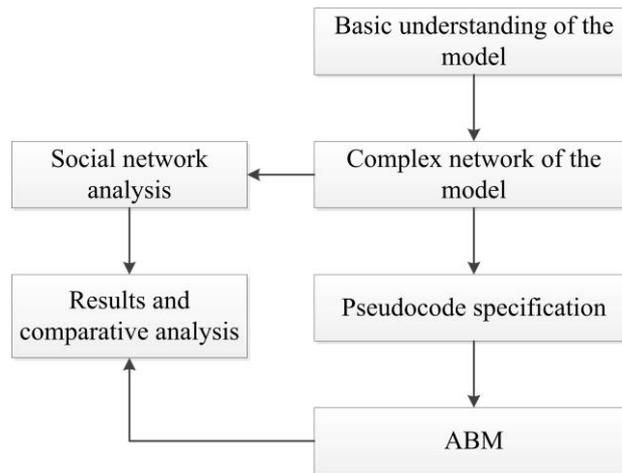
Descriptive agent-based modeling (DREAM) is a cognitive agent-based computing approach developed in [3]. DREAM offers an ABM specification technique which comprises of developing a complex network of the ABM, pseudocode specification models and social network analysis of the network model. It offers a detailed description of ABM as well as visual based analysis. It provides an easy translation of the network model into pseudocode followed by ABM development. In Figure 1, DREAM methodology is shown.

### **OVERVIEW, DESIGN CONCEPT AND DETAILS**

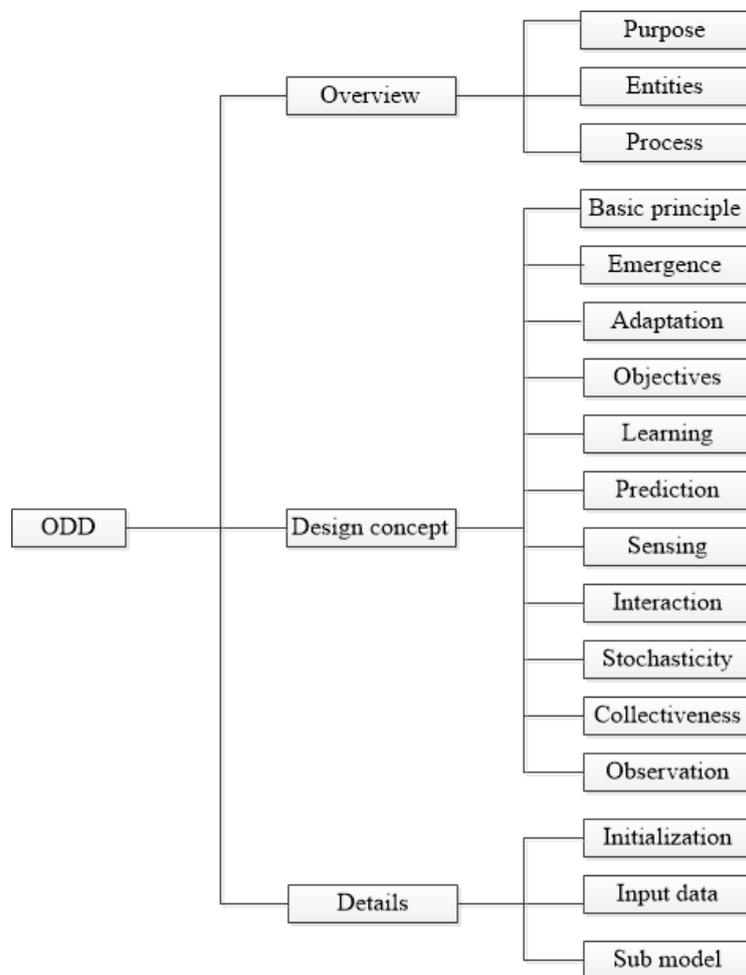
Overview, Design concept and Details (ODD) is originally developed by [6] and an updated version is presented in [8]. It is a textually based specification technique for documenting ABM. It provides a checklist which covers key features of the model. It comprises of three main sections which are Overview, Design concept, and Details. These sections are further divided into subsections. Figure 2 presents the ODD specification methodology. A detailed description can be found in [8].

## **MODEL DEVELOPMENT**

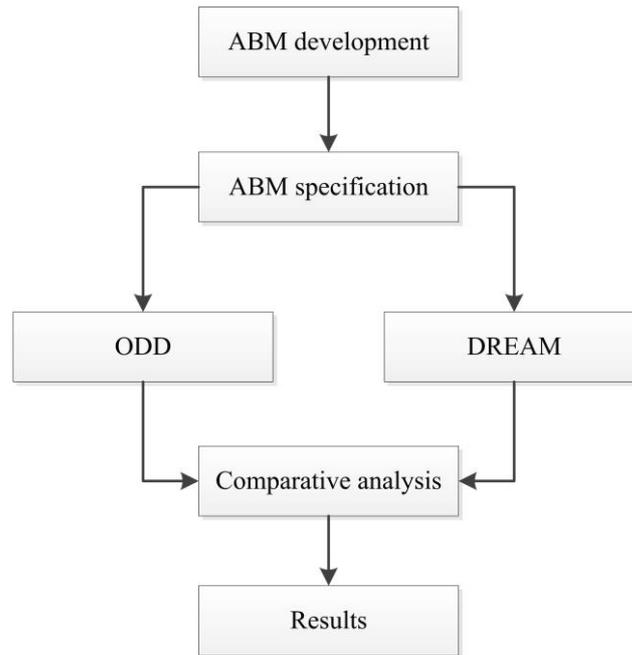
In this section, we present a case scenario of the smart grid, followed by ODD and DREAM specification of the model. Figure 3 shows our research methodology. First, we start by describing the case model from the smart grid domain. Then, we present a model specification



**Figure 1.** DREAM methodology for ABM specification adopted from [3]. It can be noticed that it starts from a basic understanding of the model, then followed by developing a complex network of the model. There are two steps after network formation, one is to present pseudocode specification, this step allows for the actual code translation, the other is applying social network analysis tool to compute centrality measures of the network. The final step involves the analysis of the results.



**Figure 2.** An ODD methodology for ABM specification adopted from [8]. It can be noticed that ODD is divided into three main sections: overview, design concept, and details. Then each section is further divided into subsections. These sections cover key features of the model.



**Figure 3.** Our research method. It can be noticed that the first step comprises of ABM development followed by the specification of the ABM. Two specification methods are adopted (ODD and DREAM). After specification, the next step is to compare and analyze both specifications approaches qualitatively as well as quantitatively. The final step shows the results of the comparative analysis.

using ODD and DREAM approaches. Through specification methods, we provide guidelines for ABM development of the case scenario. The specification study is complemented by an ABM for the scenario. Finally, the comparative analysis of specification methods as well as simulation results is provided.

### SCENARIO OF SMART GRID

To model a smart grid, let us consider a large set of networks, in which different consumers and power generation units are connected with each other through different configuration. To model possibilities of a different configuration of the large-scale power system, we use standard complex networks such as small-world [9], scale-free [10], and random network [11]. For validation, we apply routing technique such as random walk and centrality-based routing.

The routing process involves the selection of a path from the source toward the destination. Routing strategy in complex networks can be categorized into two types, i.e. Local and Global Routing. The local routing strategy needs local information about neighbor nodes. These include local static routing, local dynamic routing, and local pheromone routing [12]. On the other side, the global routing strategy needs global information like topological structure, characteristics of each node and real-time information. These include shortest path routing, efficient routing, and global dynamic routing [13].

For large-scale complex networks, global routing remains problematic. It is difficult to have the characteristics of each node and to have real-time information. Another difficulty consists in the increases in computational time. While on the other hand, local routing remains promising for large-scale real-world complex networks. It offers less computational time as well as easy implementation.

In a smart grid environment, two types of routing occur. The one is energy demand from the consumer's side to the generation unit, while the generation unit responses by providing

energy to consumers. The second is data and information routing about demand profile from consumers and energy cost from grid unit [14].

## **MODEL SPECIFICATION ACCORDING TO ODD**

In this section, we present the model specification by following the ODD model. In table 5, we summarize the ODD specification of the understudy model.

### **The overview section of ODD**

- 1) The purpose of the model: To understand how a combination of agent-based and complex network-based modeling approaches can be used to simulate large-scale power system. Further, how routing techniques can be used to validate the model.
- 2) The involved entities: The model consists of three types of agents named; consumers, producers, and walkers that are represented by nodes in a complex network. The model allows producers and consumers to be generated randomly in a network. Producers generate power and can transmit to the consumers through communication lines that we called links. Consumers demand and finally use energy power. The environment is set as a complex network where nodes represent producers and consumers and links represent transmission lines. State variables `visited?` and `consumer?` are used to mark once a node being visited and to check is any available consumer? – a node in the neighbor list. It is a convention (coding standard for NetLogo) to define a variable name ending with a question mark.
- 3) Routing purpose: For routing purpose, the concept of walkers is deployed. Initially, the walkers are located at the producer's nodes. They search for the neighbor nodes and move to one of the neighbor's node. Once a node is visited, it is marked as `visited?` The walkers also check for the consumer's node. The simulation time is kept as continues. By continues method, the NetLogo continuously updates the plots. At each time step, plots are generated in order to measure visited nodes and visiting consumers.

### **Design concept section of ODD**

- 1) **Basic principles:** The basic hypothesis of our model is that a cognitive agent-based computing approach is better for modeling and simulation of the large-scale power system. In our approach, we used a combination of agent-based and complex network-based modeling approaches. We developed complex network models such as small-world, scale-free, and random network to simulate a smart grid based environment.
- 2) **Emergence:** The “emergence” feature shows information about “what kinds of outputs of the model are modeled?” In other words, we can say what the expected results from the model are? In the case of our approach, the routing techniques (random walk and centrality routing) are used for transmission from producers towards consumers. The key results are the computation of end to end delivery from producers towards consumers.
- 3) **Adaptation:** Adaptive feature of the model shows decision-making capability for the agents against the changing environment. Decisions are taken by using well-defined constraints to adapt the variation in the environment accordingly. There are two rules applied to make a decision. When using a random walk, the walkers search for neighbor's node and select one of them, while by using centrality routing, the walkers search for a neighbor node with maximum value and select that one.
- 4) **Objectives:** In a changing environment, individual agents also receive effects or rewards from the environment for their adaptive behavior to achieve one's objective. In our model, the main objective is to measure how much time is taken while moving from one node to another.

- 5) **Sensing:** In the decision-making process among agents, there are some specific features related to each agent which allow communicating neighbor to make their decision according to the value of those features. In our case scenario, the walkers use the sensing property, if a neighbor node is already been visited then they avoid rerouting. They also sense for consumers if any visited node is a consumer, then they deliver packets or energy.
- 6) **Interaction:** Producers and consumers can communicate with each other for power transmission.
- 7) **Stochasticity:** The routing process is modeled as random.
- 8) **Observation:** When the simulation is running, at each time step the following data are collected.
  - A number of nodes.
  - A number of producers.
  - A number of consumers.
  - A number of walkers.
  - A number of nodes visited.
  - A number of consumers visited.

### The details section of ODD

The details section of the ODD specification covers features of the model about what is the initial state of the model, what kind of data is used, and what types of parameters and parameters values are set in the model.

- 1) **Initialization:** the model is implemented in NetLogo agent-based modeling tool. The model environment is initialized by calling “draw-network” method. This method is used to draw any selected network. Then consumers and producers are generated randomly by specifying their number. After this, the walkers are placed at the producer’s location.
- 2) **Input data:** the standard complex network are generated and kept as external source files. These network files are used as input for the model.
- 3) **Submodels:** the model parameters and parameters values are given in Table 1.

**Table 1.** Evaluation metrics: These parameters and parameter values are used for model simulation. The region shows the simulation environment which is kept as 100 by 100. The number of nodes in the network is considered as 500. The numbers of power sources and consumers used are 10, 50, 100, 150, 200, 250, 300. Three different standard complex networks are used. For routing purpose, random walk and centrality-based routing algorithm are applied. The Performance of the model is measured in term of average delivery rate (computation time from sources to the consumers). A series of experiments were carried out with the simulation model.

Parameter	Value
Region	100X100
No. of Nodes	500
Power sources	10, 50, 100, 150
Power consumer	50, 100, 150, 200, 250, 300, 350
Network	small-world, scale-free, random network
Routing	random-walk, centrality-based routing
Performance measure	Average delivery rate
No. of runs	4(1; 10; 20; 30) runs

### MODEL SPECIFICATION ACCORDING TO DREAM

In this section, we present our ABM documentation according to DREAM specification approach. We describe our model using pseudocode specification part of the DREAM as follows.

## Agent design

There are two types of agents which are used in the simulation model. *Agents by node types:* in our simulation model, we used complex networks. These complex networks consist of nodes which are connected through communication lines called links. These nodes agents represent producers and consumers in the network. *Agent by walker type:* for routing purpose the walker concept is deployed. These walkers were initially placed on producers nodes. They have the ability to move around the network.

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**Algorithm 1 Breed Node:** This node agent is used to represent producers and consumers in the network

---

*Internal Variables:* < source?, target?, visited? >

- 1: **source?:** All nodes that represent sources (used for producers)
  - 2: **target?:** All nodes that represent target (used for consumers)
  - 3: **visited?:** Used to check the status of a Node agent
- 

In the Node specification model, first, we described the Breed Node agent. The “Breed” is a global keyword in NetLogo (Agent-based modeling toolkit) describing a set of similar-behavior agents. As we already noted, nodes are used in the network to represent producers and consumers. After this, we specified the internal variables for the Node agent. There are three internal variables used for the Node agent. The source? variable is used to represent producers or generating unit in the power system. The target? variable is used to represent consumers in the power system environment. The last one visited? is used to check the status of the node agent whether it is visited or not. Next, we define a specification for the Walker agents.

---

**Algorithm 2 Breed Walker:** This agent is used for walker that can move around the network

---

*Internal Variables:* < location, is-finish?, location-list? >

- 1: **location:** Keep current location information of the walker
  - 2: **is-finish?:** Check the finish goal
  - 3: **location-list:** Keep all visited locations record
- 

The breed Walker represents Walker agents. These walkers are deployed for routing purpose and can move around the network. Next, we specified three internal variables for the walker agents. The first one is the location. The location variable is used to keep the information about the current location of a walker. The is-finish? is a Boolean variable that returns true if the finish condition is met? The location-list is a list variable that is used as a memory with a walker. This variable keeps the information about all visited locations. After describing the agent specification model, next, we are going to present global variables specification model

## Global

For the simulation setup, the key variables are five input global variables.

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**Algorithm 3 Input Globals:** < *get-network-type, num-node, num-walker, num-source, num-target* >

---

*Chooser:*

**get-network-type:** Used for selecting network type from the given list

*Slider:*

**num-node:** Used for specifying number of nodes in a network

**num-walker:** Used for specifying number of walkers in a network

**num-source:** Used for creating number of producer nodes

**num-target:** Used for creating number of consumer nodes

---

Here, five input global variables are used. The *get-network-type* is input provided by “Chooser” (GUI element of NetLogo toolkit). This is used for selecting the network type from the available list. The network list comprises of the small-world, scale-free, and random network. The other four input variables are provided by “Slider” (GUI element of NetLogo toolkit). The *num-node* is used to specify the number of nodes in the network. The *num-walker* is used to specify the number of walkers in the network. The *num-source* and *num-target* are used for the specification of the number of producers and consumers respectively.

### Setup procedure

Here, we present the main setup procedure for model initialization.

---

**Algorithm 4 Procedure setup:** Creating simulation environment

---

*Input:* All global parameters from the user interface

*Output:* Setup simulation environment

**begin**

- 1: clear screen
- 2: draw-selected-network
- 3: add-sources
- 4: add-targets
- 5: calculate-centrality

**End**

---

The setup procedure is the global simulation setup specification model. This is used to create the simulation model. The input parameters are provided by the user interface. The procedure starts with calling the *clear-all* function. It clears all the previous work. Next, all four individual procedures are called. The first one is “*draw-selected-network*”. Next, we describe these individual procedures.

**Algorithm 5** Procedure **draw-selected-network**: Creating the desired network*Input*: network-file, list of available network*Output*: Setup the selected network**begin**

```

1: if network-type = "small-world" then
2:   [draw-small-world]
3: else
4:   if network-type = "scale-free" then
5:     [draw-scale-free]
6:   elsenetwork-type = "random-network"
7:     [draw-random-network]

```

**End**

“draw-selected-network” is a procedure which is used to set up the selected network from the given options (a list of networks). The procedure checks the input type and calls the appropriate function. Here, three individual procedures are used. Next, we present the specification models of these individual procedures which are called by draw-selected-network procedure.

**Small-world network**

In this network topology, any individual is linked to any other individual by a maximum of six edges. In social network terminology, this is called “six degrees of separation”. It has fewer nodes with more links. It is specified by:  $G(V;E), Lalog(N)$ .

**Algorithm 6** Procedure **draw-small-world**: Creating small-world network*Input*: N*Output*: Setup small-world network

```

create-nodes N;
for all Nodes do;
set all-wired? false;
  while all-wired? != true do
    wired-them [connect-nodes];
    set all-wired=Do-calculation [clustering-coefficient];
    Findclustering-coefficient;
    If no Node left then stop;
end
create link with one node to other
calculate shortest path [set node i=1;
count distance of node i to every other node;
i++;
set shortest path=min distance]
set layout circle;

```

**End****Scale-free network**

In this network, the number of links between individuals is uneven. There are some nodes which have dense connections, while some others have fewer connections. The dense connections are called hubs. These hubs have the tendency to join with other new nodes. This

network follows the power law of the degree distribution. The probability of joining new nodes with the existing hub can be defined by:

$$\prod(k_i) = \frac{k_i}{\sum_j k_j} \quad (1)$$

In (1),  $k_i$  represents the degree of hub  $i$ .

---

**Algorithm 7 Procedure draw-scale-free:** Creating scale-free network

---

*Input:* N  
*Output:* Setup scale-free network  
set shapes circles;  
create node 1;  
set node=nobody;  
create node 1;  
[ set node = new-node]  
**if** old-node = nobody **then**  
    [create link with old-node];  
    **while** count nodes < total-nodes **do**  
        [add nodes];  
set layout spring;  
set layout circle;  
**End**

---

### Random network

In this network, each individual node is formed randomly; there is no specific structure to be followed. This network can be formed by joining a vertex with other arbitrary vertices. Formally, a random network  $G_R(N, P)$  is framed with edges associated with likelihood  $P$ , given that  $0 < P < 1$ . The connectivity of nodes does not depend on the degree of nodes.

---

**Algorithm 8 Procedure draw-random-network:** Creating random network

---

*Input:* N  
*Output:* Setup random network  
create nodes  $N$ ;  
**for all** Nodes **do**  
    set shapes circles;  
    set location random location;  
    create-links with nodes with  $p$ ;  
    check  $p > 0$  and  $p < 1$ ;  
**End**

---

Next, we present all other procedures that describe different processes which are called by the main setup procedure.

### Setup source and target nodes procedures

Procedure “add-source” is used to setup source nodes (producers) on the network. It takes network type, nodes, links, and the number of sources from the user interface. Next, it creates the user-specified number of source nodes randomly on the network.

---

**Algorithm 9** Procedure **add-source**: Setup sources on the network

---

*Input*: network-type, num-source  
*Output*: Setup source nodes on the network  
**begin**  
    random nodes[  
        set source true];  
**End**

---

Procedure “add-target” is used to setup target nodes (consumers) on the network. It takes network type, nodes, links, and the number of targets from the user interface. Next, it creates the user-specified number of target nodes randomly on the network.

---

**Algorithm 10** Procedure **add-target**: Setup targets on the network

---

*Input*: network-type, num-target  
*Output*: Setup target nodes on the network  
**begin**  
    Select random nodes[  
        set target true];  
**End**

---

After setting source and target nodes on the network, the main setup procedure calls “calculate-centrality” procedure. Next, we present the calculate-centrality procedure.

### Centrality measure

The centrality measure is widely used for measuring the relative importance of nodes within a network. It is a numerical number assigned to each node necessary for pair-wise comparisons with the whole network. There are four types of centrality measures in our model.

- 1) Degree centrality of nodes: it measures the total number of connections that a particular node has in a network. A node with a higher degree has more importance as compared with those which have a lower degree. If a node with a higher degree is removed, then it can disrupt the structure as well as the flow of the network.

---

**Algorithm 11** Procedure **calculate-degree**: Calculates degree centrality on the network

---

*Input*: selected network  
*Output*: calculates degree centrality for all nodes  
**for all** Nodes **do**  
    set degree **count** all connected links  
    set label degree  
**End**

---

- 2) Closeness centrality of nodes: it is used to find out how much data from a particular node  $I$  move to every other node  $t$  in a network. Mathematically, it can be written as:

$$C_{closeness(i)} = \sum \frac{1}{dist(i,t)}. \quad (2)$$

---

**Algorithm 12** Procedure **calculate-closeness**: Calculates closeness centrality on the network

---

*Input*: selected network  
*Output*: calculates closeness centrality for all nodes  
**for all** Nodes **do**  
    set closeness  $C_{closeness(i)} = \sum \frac{1}{dist(i,t)}$   
    set label closeness

**End**

---

- 3) Between centrality of nodes: between centrality is the process of counting the number of times a specific vertex comes in the shortest path between any two vertexes in a network. It has the capability to observe the network transmission. Mathematically, it can be written as:

$$C_{betweenness(i)} = \sum \frac{\delta_{st}(i)}{\delta_{st}}, \quad (3)$$

where  $\delta_{st}(i)$  denotes the number of shortest paths between nodes  $s$  and  $t$  passing through the node  $I$ , while  $\sigma_{st}$  is the total number of shortest paths that exist between nodes  $s$  and  $t$ .

---

**Algorithm 13** Procedure **calculate-betweenness**: Calculates betweenness centrality on the network

---

*Input*: selected network  
*Output*: calculates betweenness centrality for all nodes  
**for all** Nodes **do**  
    set betweenness  $C_{betweenness(i)} = \sum \frac{\sigma_{st}(i)}{\sigma_{st}}$   
    set label betweenness

**End**

---

- 4) Eigen-vector centrality of nodes: it measures the impact of a particular node in a network. It defines which node is connected to the most important node in a network. It depends on neighbors in term of connection that neighbors have with other nodes in a network.

---

**Algorithm 14** Procedure **calculate-eigenvector**: Calculates eigenvector centrality on the network

---

*Input*: selected network  
*Output*: calculates eigenvector centrality for all nodes  
**for all** Nodes **do**  
    set eigenvector  $C_{eigenvector(i)} = \frac{1}{\lambda} \sum_{t \in g} A_{adj-matrix} * X_t$  OR  $Ax = \lambda x$   
    set label eigenvector

**End**

---

## Procedure go

To validate our model, we apply routing techniques on our developed models. There are two routing techniques that we used in our work. The first one is a random walk and the second one is centrality-based routing. Next, we present the details and specification models of these two routing techniques described as procedures.

- 1) Procedure random-walk: in case of a random walk, the walkers are set initially on the source nodes. They search their neighbors and select one of them randomly. This process goes repeatedly until all the target nodes have been visited. Let us consider an undirected graph  $G(V, E)$ , a random walk is a stochastic process that starts from a given vertex, then select one of its neighbors randomly to visit next. It has no memory that keeps information on previous moves. It stops when the termination condition meets.

---

**Algorithm 15** Procedure **random-walk**: Used for routing on network

---

*Input*: All input parameters provided by user interface

*Output*: End to end delivery from sources to the destinations

*Execution*: Called repeatedly on simulation execution

**begin**

- 1: start from sources
- 2: **while** *is – finish*  $\neq$  *true* **do**
- 3:     search neighbors
- 4:     select any of neighbor
- 5:     **move** to the selected

**End**

---

- 2) Procedure centrality-rw: the procedure “centrality-rw” is another approach which is used in our work for the routing purpose. The technique works as follows. The walkers search for that neighbor node which has maximum centrality value, then move to the selected node. If they find no node with maximum centrality value, then they select randomly a node from the neighbors. The process of centrality-based routing is shown in Figure 4.

---

**Algorithm 16** Procedure **centrality-rw**: Used for routing on network

---

*Input*: All input parameters provided by user interface

*Output*: End to end delivery from sources to destinations

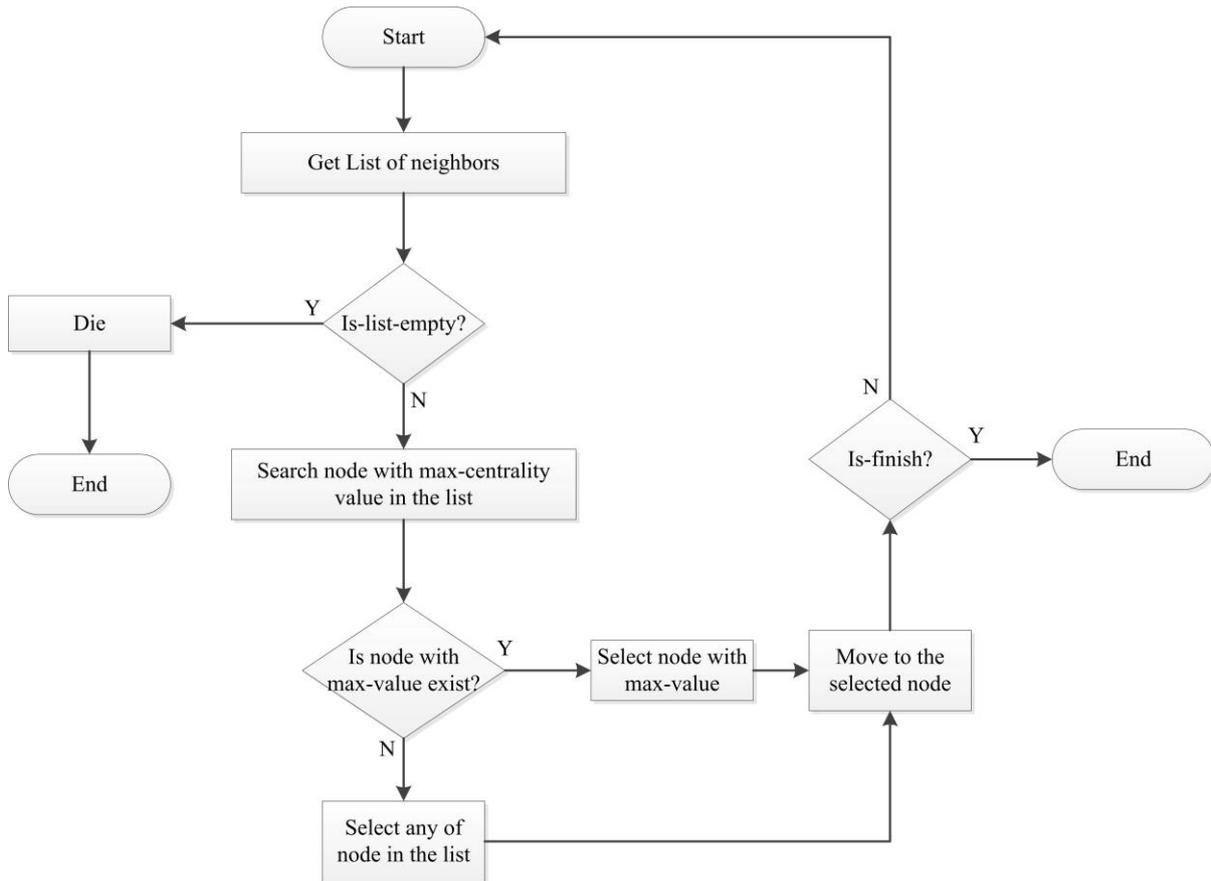
*Execution*: Called repeatedly on simulation execution

**begin**

- 1: start from sources
- 2: **while** *is-finish*  $\neq$  *true* **do**
- 3:     get-list-of-neighbors
- 4:     **if** *is-list-empty*=*true* **then**
- 5:         die
- 6:         stop
- 7:     Else
- 8:         Search node with max-centrality in the list
- 9:         **if** node with max-value exist= *true* **then**
- 10:             select node with max-value
- 11:         Else
- 12:             select any of node in the list
- 13:             **move** to the selected

**End**

---



**Figure 4.** Flowchart for the centrality-based routing algorithm. We can see that the algorithm starts with making a list of neighbor nodes of the current location. In the next step, it checks the content of the list. If the list is empty, then the simulation stops, otherwise, the algorithm searches for the node having maximum centrality value. If such a node exists, it selects that node, otherwise, it selects any node from the neighbor’s list. The next step is to move to the selected node. After this, it checks the terminating condition. If it is satisfied, the simulation stops, otherwise the control goes to the first step.

3) Generate plot: “dot-plot” procedure is used to plot the execution of the simulation of the model. Here, this procedure plots two types of information. First, at each time step, it counts the number of nodes that have been visited. Second, it counts the number of consumers that are visited. Next, we present model specification and details the experiments with our model

---

**Algorithm 17** Procedure **generate-graph**: Generate graphs of the current simulation state

---

*Input:* No input required

*Output:* Generate plot on simulation execution

*Execution:* Called by Go procedure

**begin**

Plot the number of nodes that are visited

Plot the number of targets visited

**End**

---

**Performed experiment**

Two types of experiments are performed in our model simulation. The first one is used for the random walk algorithm, the second is used for the centrality-based routing algorithm.

**Algorithm 18** Experiment: Demonstrates the effect of random walk and centrality routing on different networks

*Input:*  $\langle \text{num} - \text{nodes}, \text{num} - \text{sources}, \text{num} - \text{targets}, \text{num} - \text{walkers}, \text{network} - \text{type} \rangle$   
*Setup Procedure:*  $\langle \text{setup} \rangle$   
*Go Procedure:*  $\langle \text{random} - \text{walk}, \text{centrality} - \text{rw} \rangle$   
*Repetition:* 10

*Input:*

**num-nodes:** 500  
**num-sources:** 10, 50, 100, 150  
**num-targets:** 50, 100, 150, 200, 250, 300, 350  
**num-walker:** 10, 50, 100, 150

**network-type:** small-world, scale-free, random-network

*Reporter:*

**measure-nodes:** count number of nodes that have been visited  
**measure-targets:** count number of targets that have been visited

*Stop condition:*

If all targets are visited, Stop

### CENTRALITY-BASED ROUTING ALGORITHM: TIME COMPLEXITY ANALYSIS

In this section, we present the centrality-based routing algorithm time complexity analysis. The time complexity of our proposed centrality-based routing is a linear function of  $n$  that is  $O(n)$ . In the algorithm analysis, we analyze the cost and number of times that each step takes for execution. All steps take constant time, except steps 2 and 8 which take  $n$  times for execution. In step 2, the while loop executes  $n$  times. In step 8, the algorithm searches the list of nodes and then selects the node with the largest value. So it takes  $n$  times. The total running time is the sum of the running times and costs of each step in the algorithm.

Procedure **centrality-rw**: Used for routing on network

*Input:* All input parameters provided by user interface  
*Output:* End to end delivery from sources to the destinations  
*Execution:* Called repeatedly on simulation execution

<b>begin</b>	Cost	time
1: start from sources	$C_1$	1
2: <b>while</b> $is - finish \neq true$ <b>do</b>	$C_2$	$n$
3:     get-list-of-neighbors	$C_3$	1
4: <b>if</b> is-list-empty=true <b>then</b>	$C_4$	1
5:         die	$C_5$	1
6:         stop	$C_6$	1
7:     Else		
8:     Search node with max-centrality in the list	$C_7$	$n$
9: <b>if</b> node with max-value exist= true <b>then</b>	$C_8$	1
10:         select node with max-value	$C_9$	1
11:     Else		
12:     select any of node in the list	$C_{10}$	1
13: <b>move</b> to the selected	$C_{11}$	1

**End**

$$T(n) = C_1(1) + C_2(n) + C_3(1) + C_4(1) + C_6(1) + C_7(n) + C_8(1) + C_9(1) + C_{10}(1) + C_{11}(1) \quad (4)$$

$$c = (C_1 + C_3 + C_4 + C_5 + C_6 + C_8 + C_9 + C_{10} + C_{11}) \quad (5)$$

$$C_2(n) + C_7(n) = (C_2 + C_7)n \quad (6)$$

$$a = C_2 + C_7 \quad (7)$$

By putting the Eq. 5 and 7 values in Eq. 4, we get:

$$T(n) = an + c \quad (8)$$

$$T(n) = O(n) \quad (9)$$

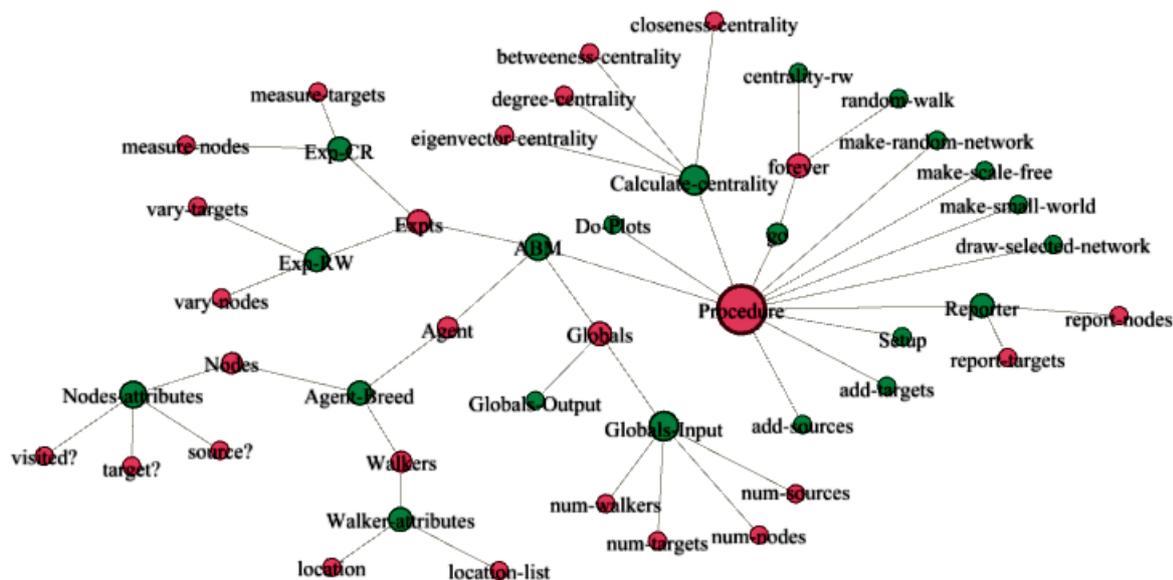
## RESULTS AND DISCUSSION

In this section, we present results obtained from the DREAM methodology, then we compare ODD vs DREAM, followed by an empirical analysis and study of some significant representative related researches.

### COMPLEX NETWORK OF THE MODEL

Figure 5 shows the complex network of our proposed ABM. This network presents the developed ABM in a visualized form. We develop the network model using Gephi (a network toolkit).

First, we start from the root node “ABM”. This node is expanded into leaf nodes “global variables, agent, procedure, and expts”. The global variables are further expanded into global output and input. These are inputs provided by the user interface to the model. The “agent” node represents the involved entities in the model and it is further expanded into two types of agents that are named as node and walker. After defining global inputs, agent, our next focus is on the “procedure” node. The “procedure” node is the root of all procedures used in the model. This node has the highest node degree in the network model. The node “expts” is the parent for all sub-nodes that represent different experiments carried out during simulation.



**Figure 5.** The network model of our proposed ABM for the smart grid. It can be noticed that the root node in the network is “ABM” which is connected to four nodes named “globals, agents, procedure, and expts”. The “globals” node is connected to the globals output and input parameters. The “agent” node is connected with the involved entities in the model. The “procedure” node is connected with all other processes and functions in the model. The “expts” node is connected with all experiments carried out in the model simulation.

## **SOCIAL NETWORK ANALYSIS**

In this section, we present the results obtained by applying social network analysis (SNA) on the network model. The SNA provides quantitative measures to give network topological details. Using these quantitative measures we can perform a comparison of different models.

In Figure 8 degree centrality of the network is plotted. It shows that the procedure node has the highest centrality. Next is the ABM node and third the global input.

In Figure 9 betweenness centrality is presented. It demonstrates that the ABM node has the highest betweenness centrality and the procedure node exhibits the second highest betweenness centrality.

Figure 10 shows the closeness centrality of the network model. It demonstrates that the ABM node has the highest closeness centrality and the procedure node is the second.

Figure 11 shows the eigenvector centrality of the network. It shows that the procedure node has the highest eigenvector centrality followed by the ABM node.

## **COMPARISON OF ODD AND DREAM**

In this section, we provide a qualitative as well as a quantitative comparison between ODD and DREAM specification techniques.

The ODD specification allows a textual-based description of ABM with the purpose to make model readable and it promotes the rigorous formulation of models. It comprises a checklist that covers key features through which one can describe an ABM. The ODD specification also has some limitations that are described in the following.

The ODD specification only provides a textual-based description of ABM. Sometimes for large ABMs, such textual-based description is insufficient to cover all the features of the ABM. It has no quantitative assessment of the ABM on the basis of which one could perform a comparison between different ABMs. Reviewing and comparison of different ABMs are difficult. For comparison and classification purposes, the only possible way is to make a table and put together ODD checklists of different ABMs and then search for similarities and differences.

According to [8], a survey was conducted from 2006 to 2009 of those publications in which ODD was used. According to this survey, only 75% of publications used ODD correctly, while 25% of publications used ODD incorrectly and some parts of the method were compromised. The author formulates the conclusion that it is difficult to write an ABM specification by following ODD method.

Another issue which is identified in the ODD specification is redundancy. Some parts of the specification like the purpose section are also included in the introduction section of the document. The design concept section is also repeated in the sub-model section of the model. The sub-model section is repeated in the process of scheduling sections.

Sometimes there may be different publications with a different version of the same ABM. Then these publications have the same ODD with little modification in the entities and process sections. Another limitation of ODD is that the textual-based description is too specific which is not useful for replication of ABMs; there exist some ambiguities and misunderstanding about ABMs.

On the other side, DREAM allows a detailed specification of ABMs. It comprises of making a complex network of the model, pseudocode specification, and network analysis steps.

This method allows for inter-disciplinary comparative study and communication among different scientific domains. So, if a model is developed in social science, it can be compared visually and quantitatively with a model in biological science and vice versa. For instance,

the social model for aid spreading presented in [15] and biological model developed for the emergence of snake-like structure in [15], by developing complex networks of both ABM models, we can easily compare and analyze both networks in the same manner. DREAM specification approach can be applied to any ABM of any research domain.

DREAM allows presenting ABM in the form of a complex network model. This allows reading and understanding ABM visually without going to the code specification. Performing network analysis on this network of ABM, it also gives a quantitative measurement of the ABM. These quantitative measures are the digital footprint of ABM and can be used to compare different ABMs.

DREAM further allows pseudocode specification and details of the ABM. This specification helps to understand ABM completely and independently of a particular scientific discipline. This specification then offers a translation to the code and facilitates further developing of ABM. It follows that by using DREAM, any ABM can be replicated easily.

Next, we carry out an empirical assessment of ODD and DREAM specification methods, using an evaluation method presented in [17]. In the study, the author presented an empirical analysis of the Ontology-engineering methodologies using different key features as presented in Table 2. That is the first reason we also used the same feature in our study. We selected 10 key features that are desirable and being good for the specification methods.

The purpose of methodologies assessment is to identify which features in the methodology to what extent. In other word, we only consider the level of the feature offered by the specification methodology. We used  $H = 2$ ,  $M = 1$ , and  $L = 0$  for evaluation purpose that demonstrates which methodology offers which features to what extent. For example, if a methodology fully support a specific feature, we assign it  $H$ , if a methodology partially support a specific feature, we assign it  $M$ , and if a methodology does not support a specific feature, then we assign it  $L$ . In last, we compute the rank of each methodology by averaging the results as shown in table 3. The description of the weight assignment is given as follows.

### **Social and technical process**

Both ODD and DRAM provide a description of social and technical processes in the specification, so we assign weight  $H$  to both methods.

### **Adaptability**

The DREAM approach is so flexible that can be adopted in the different scientific domain. The pseudocode specification of DREAM allows researchers to implement the model in any programming language. On the other side, the ODD method is a textual-based approach does not target multiple scientific domains. In previous studies, the ODD method is only reported mostly in social sciences. In the evaluation process, we assign  $L$  and  $H$  to ODD and DREAM respectively against the adaptability feature.

### **Reusability**

In the case of reusability, it can be noted that the ODD specification cannot be used for further development of the models, while the DREAMs pseudocode specification can easily be used for the development purpose. In this case, we assign  $L$  and  $H$  weight to ODD and DREAM, respectively.

### **Stepwise approach**

Both ODD and DREAM provide sequential steps for documenting a model. That's why we assign equal weight to both ODD and DREAM against the stepwise feature.

## Documentation

The ODD offers insufficient documentation of the model while DREAM covers the complete specification in the documentation process. In this case, we assign weights  $M$  and  $H$  to ODD and DREAM respectively against documentation feature.

## Network model

The ODD does not support developing the network model of understudy system, while the DREAM facilitates researchers for developing a network model of understudy system. In this case, we assign weights  $L$  and  $H$  to ODD and DREAM respectively against the network model feature.

## Pseudocode specification

The ODD method does not support the pseudocode specification feature in the documentation process. The DREAM method offers pseudocode specification in the documentation process. In this case, we assign weights  $L$  and  $H$  to ODD and DREAM respectively against the pseudocode specification feature.

## Network analysis

The ODD method does not include the social network analysis approach during the documentation process, while the DREAM offers social network analysis feature. In this case, we assign weights  $L$  and  $H$  to ODD and DREAM respectively against network analysis feature.

## Communication

The ODD does not provide communication across different scientific domains, while the DREAM does. In this case, we assign weights  $L$  and  $H$  to ODD and DREAM respectively against communication feature.

## User satisfaction

The ODD method ignores the user satisfaction feature in the specification process, while DREAM includes user satisfaction in the specification process. In this case, we assign weights  $L$  and  $H$  to ODD and DREAM respectively against user satisfaction feature.

**Table 2.** Selected features for empirical analysis of ODD and DREAM.

<b>Feature</b>	<b>Description</b>
<i>Social and technical process</i>	Considers the level of social and technical aspects in the methodology
<i>Adaptability</i>	Referring to how much the methodology is flexible to adoption in different domains
<i>Reusability</i>	It refers to the extent of the methodology to be used for model replication
<i>Stepwise</i>	Measures how much methodology is based on sequential steps
<i>Documentation</i>	It involves the process of documenting the model
<i>Network model</i>	It is the developing of the network for the model
<i>Pseudo-code</i>	Concerns with the presenting pseudo-code specification for the model
<i>Network analysis</i>	Concerns with applying social network analysis tool on network
<i>Communication</i>	Refers to the level of communication among multiple disciplines
<i>User satisfaction</i>	Refers to the level of convenience

**Table 3.** Empirical analysis of ODD and DREAM.

Feature	ODD	DREAM
F(1)	<i>H</i>	<i>H</i>
F(2)	<i>L</i>	<i>H</i>
F(3)	<i>L</i>	<i>H</i>
F(4)	<i>H</i>	<i>H</i>
F(5)	<i>M</i>	<i>H</i>
F(6)	<i>L</i>	<i>H</i>
F(7)	<i>L</i>	<i>H</i>
F(8)	<i>L</i>	<i>H</i>
F(9)	<i>L</i>	<i>H</i>
F(10)	<i>L</i>	<i>H</i>
Rank	0,5	2,0

## EXPERIMENTAL EVALUATION

### Simulation setup

To simulate a smart grid-based complex scenario, we developed small-world, scale-free, and random complex networks using agent-based modeling approach. In order to validate our work, we applied routing techniques such as random walk and centrality-based routing on large-scale complex networks, specifically in the smart grid domain. For comparison, we applied random and centrality-based routing on these networks and analyzed their behavior on these networks.

### Evaluation metrics

For performance evaluation purpose, we used the average delivery rate parameter. The average delivery rate is defined as the number of packets sent by sources and successfully received by consumers. Mathematically, it can be written as follows:

$$\sum_1^n \frac{Ds}{Dc} 100, \quad (10)$$

where  $Ds$  represents data packets sent by the sources and  $Dc$  represents data packets received by consumers. The experiments were performed for different case studies such as different numbers of consumers and generation units. Then the simulation results were averaged over 30 executions. To see the behavior of routing techniques, when going from source locations towards the destinations through different paths at each time steps, we used different parameters and observed for which combination it took less convergence time. The simulation environment is set according to the parameters as shown in Table 1.

### Results of Random walk routing

We applied the random walk routing technique on different complex networks. The simulation results demonstrate that the random walk routing technique showed less iteration in case of small-world topology as compared to other network topologies.

For the small-world network, Figure 12a shows the simulation results for different numbers of sources and consumers. This shows the convergence rate in different case studies. The results show that the convergence rate lies between 180 and 280 iterations.

For the scale-free network, Figure 12b shows simulation results for the different numbers of sources and consumers. Random walk shows a slow convergence rate as compared to the small-world network.

For the random network, Figure 12c shows simulation results for different numbers of sources and consumers. On this network topology, random walk demonstrates very slow convergence rate as compared to both the scale-free and the small-world networks. This is due to the network topology.

Figure 12d shows the performance of random walk on different network topologies. The small-world topology demonstrates less iteration while the random network has a slow convergence rate.

### **Issues with Random walk routing**

- 1) Agents can move randomly on the network, they select a random node from their neighbor's list.
- 2) Agents can move to previously visited nodes.
- 3) Agents do not maintain records when traversing nodes of the network.
- 4) Sometimes, agents get stuck on the network, which increases computational time.

### **Results of Centrality-based routing:**

In this section, we discuss the simulation results that were carried out using centrality routing (CR) algorithms on different networks.

Figure 13 shows the simulation results based on betweenness centrality routing on different networks. For the small-world network, figure 13a shows the simulation results for different numbers of sources and consumers. The results show that the convergence rate lies between 30 to 50 iterations. For the scale-free network, figure 13b shows simulation results for different numbers of sources and consumers. Betweenness centrality routing shows slow convergence rate as compared to the small-world network. For the random network, figure 13c shows simulation results for different numbers of sources and consumers. On this network, betweenness centrality routing demonstrates very slow convergence rate as compared to both the scale-free and the small-world networks. This is due to network topology. Figure 13d shows the performance of betweenness centrality routing on different network topologies. The small-world network demonstrates less iteration while the random network has very slow convergence rate.

Figure 14 shows the simulation results based on closeness centrality routing. For the small-world network, Figure 14a shows the simulation results for different numbers of sources and consumers. The results show that the convergence rate lies between 30 to 50 iterations. For the scale-free network, Figure 14b shows simulation results for different numbers of sources and consumers. Closeness centrality routing shows slow convergence rate (between 150 and 250) as compared to the small-world network. For the random network, Figure 14c shows simulation results for different numbers of sources and consumers. On this network, closeness centrality routing demonstrates very slow convergence rate as compared to both the scale-free and the small-world networks. Figure 14d shows the performance of closeness centrality routing on different network topologies. The small-world topology demonstrates less iteration while the random network has very slow convergence rate.

The simulation results based on degree and eigenvector centrality routing on different networks have been shown in Figures 15 and 16, respectively. In case of degree and eigenvector centrality routings again the small-world network showed fast convergence rate as compared with other networks.

Figure 17a shows centrality routing on the small-world network with different numbers of consumers and generating units. The simulation results show that on average, each centrality routing has an equal convergence rate. When it is compared with other complex networks, it

is found through simulation results based on centrality routing, the small-world network has lower convergence rate compared with the other networks, in this case, centrality routing on small-world has convergence rate between 30 to 50 iterations.

Figure 17b shows simulation results of the centrality routing on the scale-free network with different numbers of consumers and generation units. The simulation results demonstrate that on the scale-free network, degree centrality routing has a slow convergence rate as compared to other approaches.

Figure 17c shows simulation results of degree, closeness betweenness, and eigenvector centrality routing applied on the random network using different numbers of consumers and generating units. The figure shows that degree centrality routing has lower convergence time as compared to other centrality routing techniques.

### **Random-walk vs Centrality-based routing**

Figure 18a shows the simulation results of different routing techniques on the small-world network. It demonstrates that centrality routing techniques have a similar convergence rate while the random walk has a large convergence rate.

Figure 18b shows simulation results of different routing techniques on the scale-free network. It demonstrates that degree centrality routing and random walk have large convergence time.

Figure 18c shows simulation results of different routing techniques on the random network. It shows that a random walk has large iterations as compared to other routing techniques.

### **COMPARISON WITH PREVIOUS WORKS**

In this section, we present an overview of the previous studies in the smart grid domain. The purpose of this section is to highlight the gaps in the current literature of the smart grid. We focus on the agent-based, complex systems and specification methods for the developing of the smart grid models. From our review, we noticed that the previous agent-based studies do not focus on the specification aspects of the models. A comparative analysis has been shown in Table 4.

In [18], the authors developed a conceptual model for the energy system. This model is integrated with the ODD methodology for documenting ABM. In this model, some other concepts were added like layers, objects, actor and working point to bridge the social and technical systems in the energy model. However, this conceptual model was not validated through ABM.

In [19], the authors proposed a check-in based routing approach for network traffic model. In this work, betweenness centrality was used to assign node as the check-in node between source and destination. The proposed routing strategy was implemented on the scale-free network. However, the optimization of routing remained an open problem in this work.

In [20], the authors presented agent-based tools for modeling and simulation of self-organization in a wireless sensor network. They demonstrated the usability of NetLogo agent-based tool and developed different experiments that show how to model different scenarios in the sensor network domain.

The paper [21], proposed a routing technique for large-scale sensor network-based environments. In this work, local and global updating strategy is introduced for maintenance and efficient routing in the network. This approach monitors any changes in the network and updating the routing path according to the situation. Results demonstrate the effectiveness of the techniques and a reduced end to end delivery rate as compared to the previous techniques.

Wang et al. in [22], worked on frequency synchronization in the power grid system. In this study, the network theory concept was used to monitor, control and exploit the frequency variation of the power system.

Jia et al. [23], worked on security analysis using complex network approach in the power system. In this work, the power adjacency matrix approach is proposed for the analysis and measurement of the power flow and activities of each node and links on the network.

In [24], the author proposed a novel routing strategy based on betweenness centrality in a complex network. In this work, scale-free network is used and routing was performed based on expanding betweenness of each node. This method shifts the load from the node with higher betweenness to the lower.

The study in [25] proposed Honey bee optimization-based routing using the random network-based environment in the smart grid domain. However, this work was not validated on different standard network topologies such as small-world, scale-free and random network. Other limitations of this study are using limited numbers of geographic spaces as well as a limited number of communication ranges.

In [26], the author proposed an efficient probability routing strategy using scale-free complex network topology. This method utilizes the probability concept for redistributing load from critical nodes to the non-critical nodes. Results showed that the routing path is reduced by 30% as compared with a previous probability routing technique.

In [27], the authors presented a novel routing strategy in the wireless sensor network and proposed sink betweenness distributed routing algorithm. In this approach, betweenness of each node is calculated in which the sink node exists as a terminal node. This work was implemented on the random network.

The study in [28], proposed a multi-agent system for the reactive power control system in a smart grid. This proposal reduced power losses and provided the exploitation of available power resources. In [29], the author presented a voltage variation control strategy. This approach controls the voltage profile in the specified range of the studied system, which results in reducing system loss and improving system reliability.

Authors in [30, 31] have worked on fault location and restoration in smart grid by using the complex network approach. These studies demonstrate the modeling of fault location and restoration process in a distributed power network. Likewise, the study [32] proposed the use of the neural network for an adaptive protective system in a large-scale power system.

Authors in [33] worked on fault location and proposed the use of particle swarm optimization the technique for locating voltage disturbance sources in a distributed power grid.

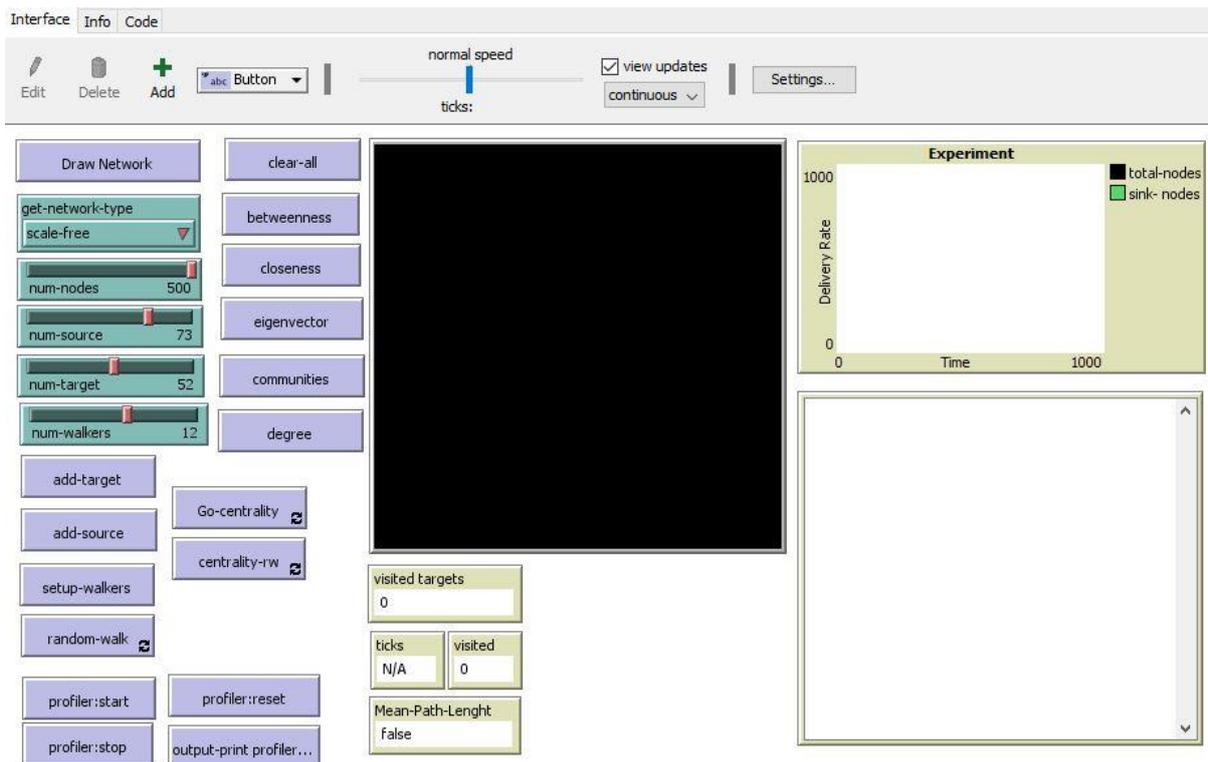
In [34], the authors proposed another novel approach for voltage diagnosis and fault detection in power distribution system. They proposed a negative selection and clonal algorithm inspired by the biological immune system. This method can learn unknown patterns in the system without going to the initial state. The results demonstrate 99% accuracy. Another study in [35] also focused on voltage stability and proposed the use of the genetic algorithm for determining optimal power sources. Likewise, another work [36] was done on contingency selection in a power system network. The proposed system was tested on an IEEE-30 test system and results showed 100% accuracy rate.

Regarding communication management, different studies also have been presented in the smart grid. Wang et al. in [37], proposed an adaptive strategy for energy trading between the utility grid and consumers. In this proposal, each agent can communicate with each other for sharing information about energy usage and cost. In [38], authors have worked on distributed

large-scale consumers load with the conjunction of renewable energy resources. In this work, a neighbor communication strategy is applied. This results in low communication cost. Kremers et al. in [39] presented a bottom-up approach for smart grid modeling. It consists of two layers; physical layer for electrical power transmission and logical layer for communication. This model has the ability to integrate new devices in the smart grid environment. It provides dynamic load management, power, communication control and monitoring.

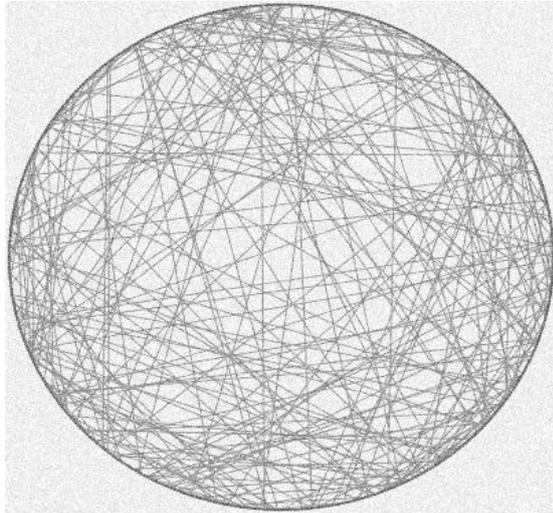
## CONCLUSIONS

In this article, we proposed a novel ABM developing approach by using specification methods such as ODD and DREAM for the smart grid system. The proposed method guides the researcher for developing an ABM starting from conceptual models to validated ABM through simulation. The work is exemplified by considering a case scenario from the smart grid system. We showed how to effectively model the smart grid system by using specification methods. We demonstrate the usefulness of the proposed approach in terms of modeling a complex system, ease of use, and knowledge transfer. The proposed method also supports communication between multidisciplinary researchers. We presented qualitative as well as a quantitative comparison of both ODD and DREAM specification techniques. The comparative study of ODD and DREAM proved that DREAM methodology is the more useful approach for documenting an ABM not only in terms of modeling but also for replication of the models, specifically in the smart grid domain.

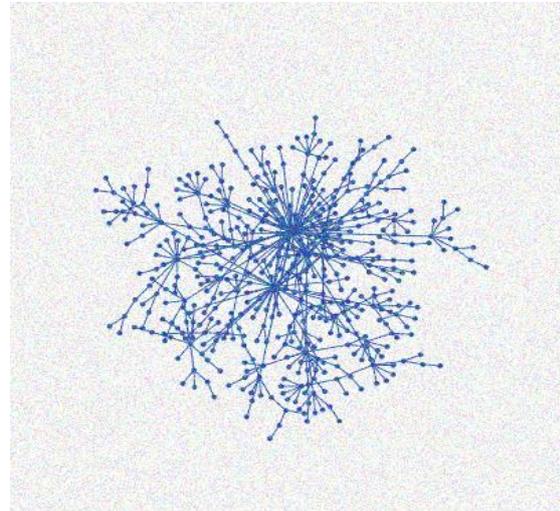


**Figure 6.** Screenshot of the developed ABM of the smart grid. The image shows the user interface of the NetLogo simulation tool. It consists of sliders, chooser, monitors, buttons, and the world ( a simulation environment).

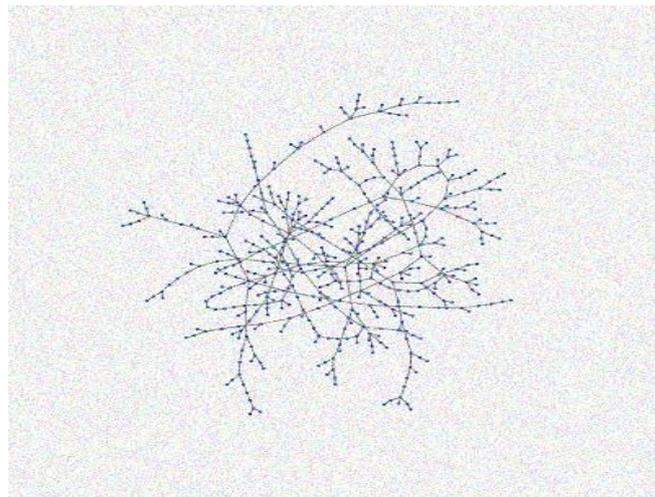
Here we would like to mention that the presented work only focuses on communication among power sources and consumers using routing approaches in the complex networks of the smart grid. However, other than communication, there are several key problems like demand response management, power scheduling, fault control, and storage management. Study on these aspects is also needed from a complex network perspective. These studies will lead to the better utility of complex networks in the smart grid domain.



(a) Small-world network

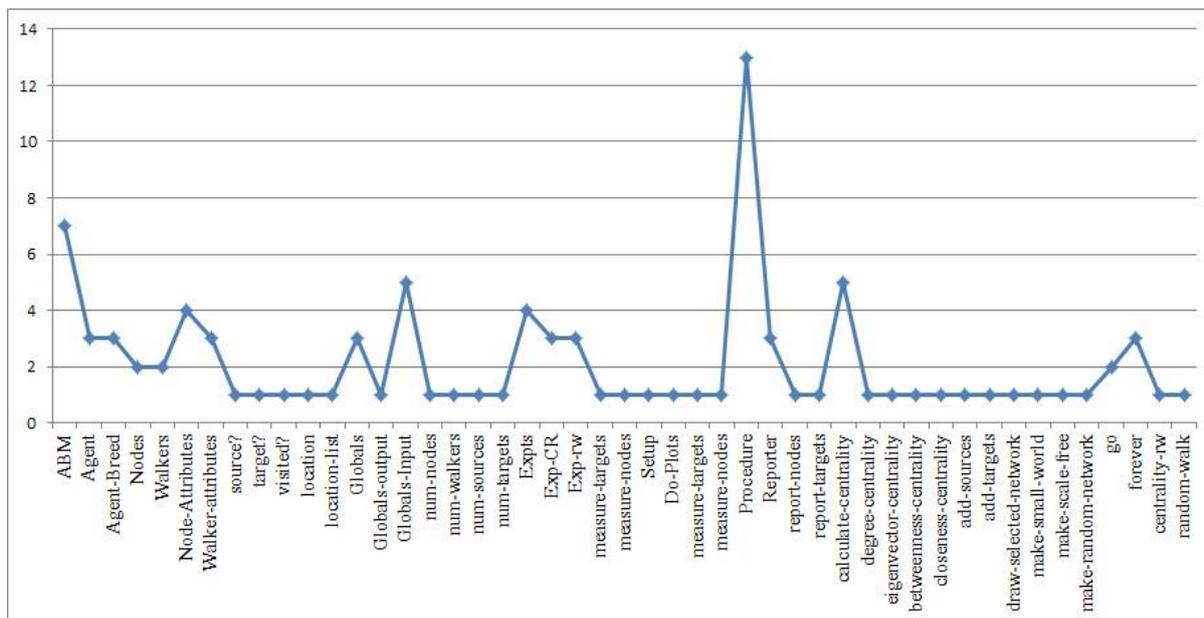


(b) Scale-free network

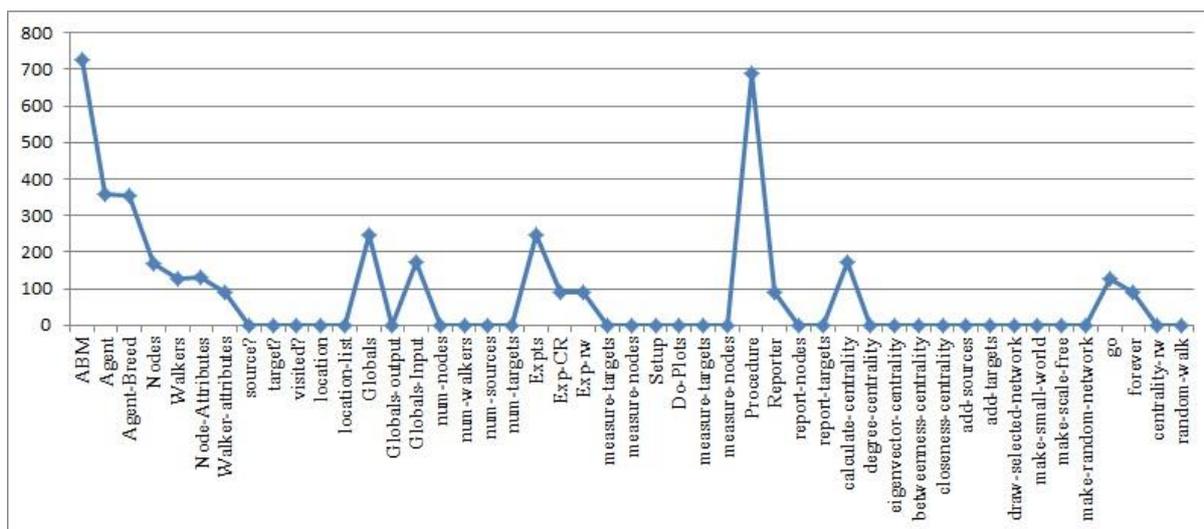


(c) Random network

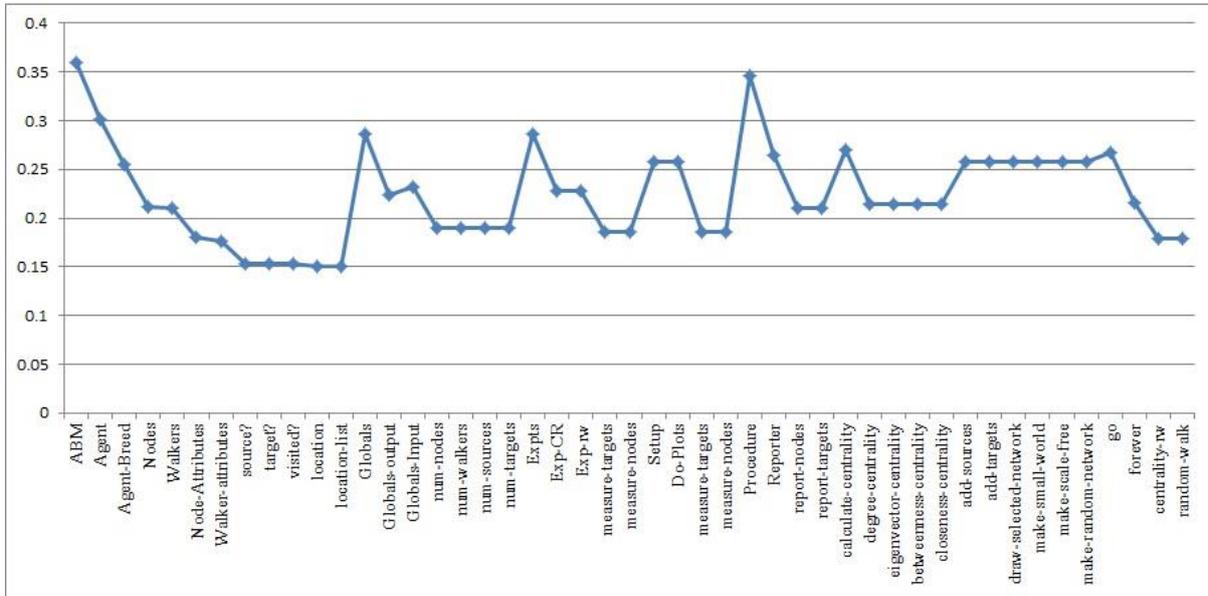
**Figure 7.** Developed smart grid scenarios based on standard complex networks in our study. These networks were developed using NetLogo tool: Part (a) shows the small-world consisting of 500 nodes, the number of consumers and sources are selected randomly. Part (b) shows the scale-free network with 500 nodes, the number of consumers and sources are selected randomly. Part (c) demonstrates the random network consisting of 500 nodes, the number of consumers and sources are selected randomly.



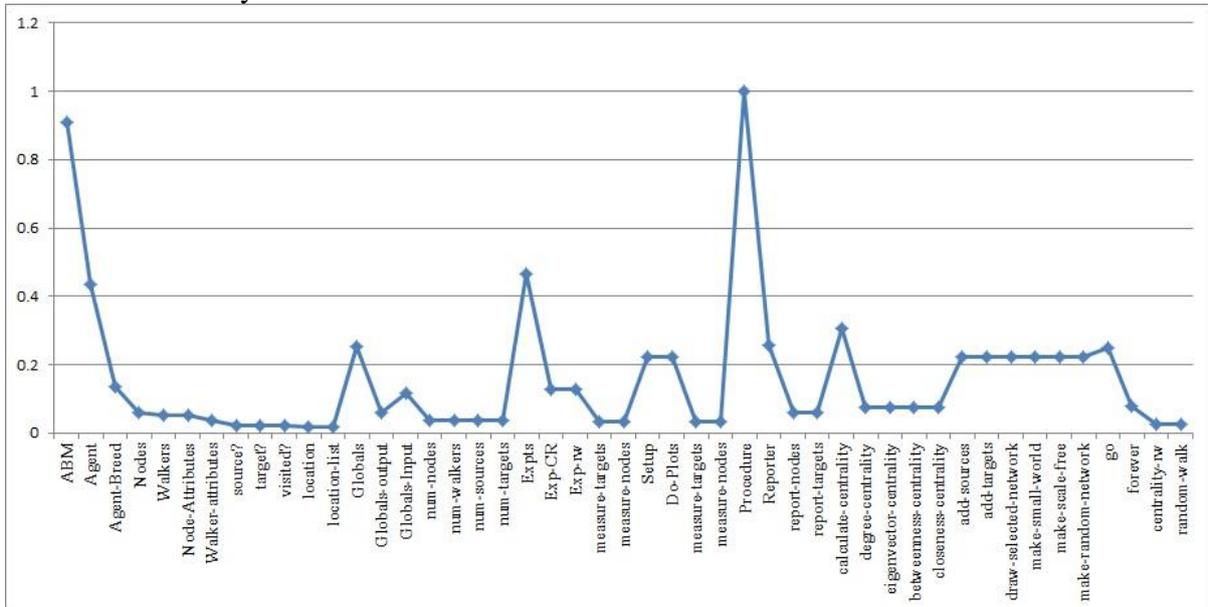
**Figure 8.** Degree centrality of the network. It shows that the Procedure node has the highest degree in the network.



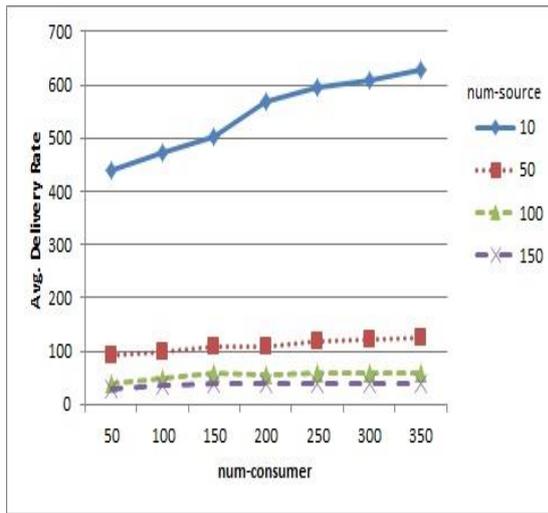
**Figure 9.** Betweenness centrality of the network. ABM node has the highest betweenness centrality value in the network.



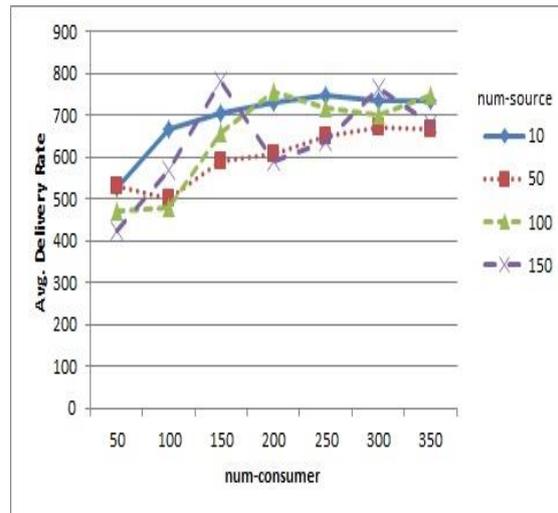
**Figure 10.** Closeness centrality of the network. ABM and Procedure node has the highest closeness centrality value.



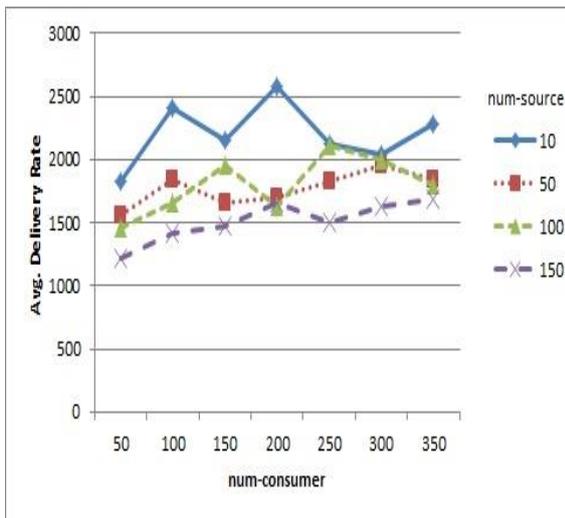
**Figure 11.** Eigenvector centrality of the network. It shows Procedure node is on the top of the list in the network model.



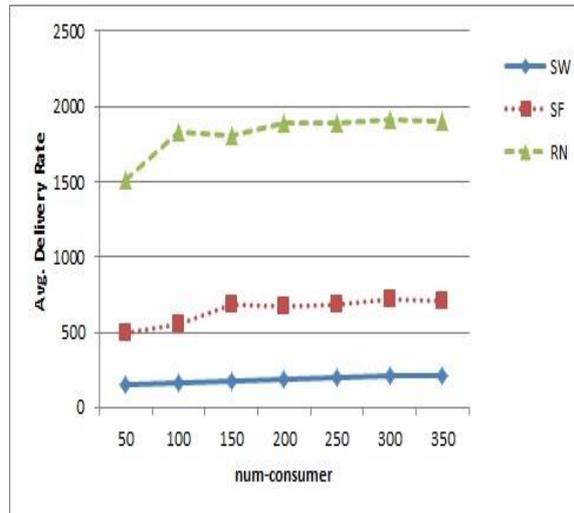
(a) Random walk on Small-world



(b) Random walk Scale-free

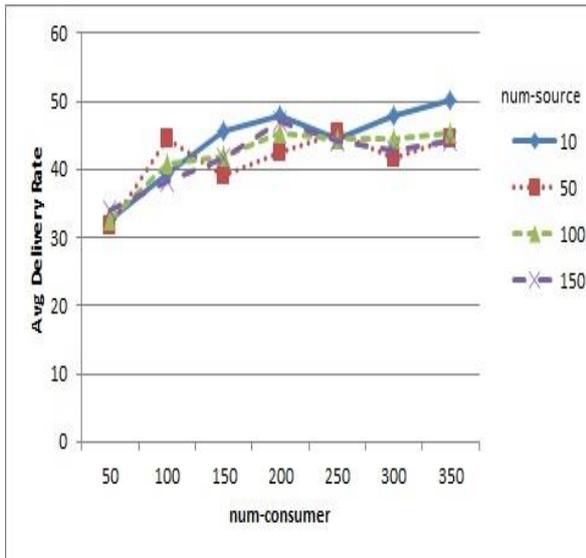


(c) Random walk on Random network

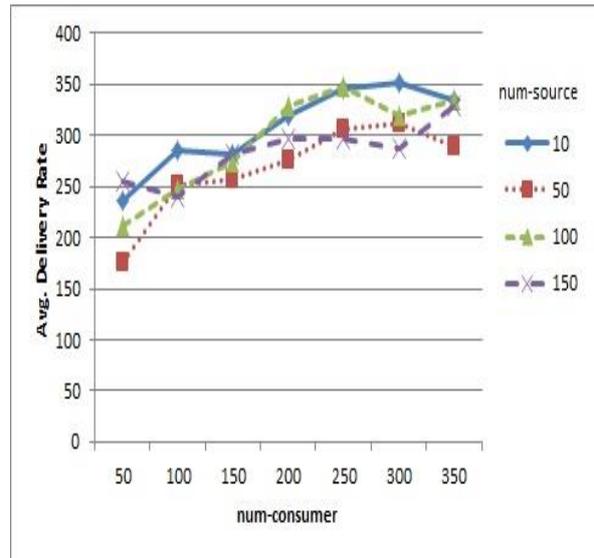


(d) Random walk on all networks

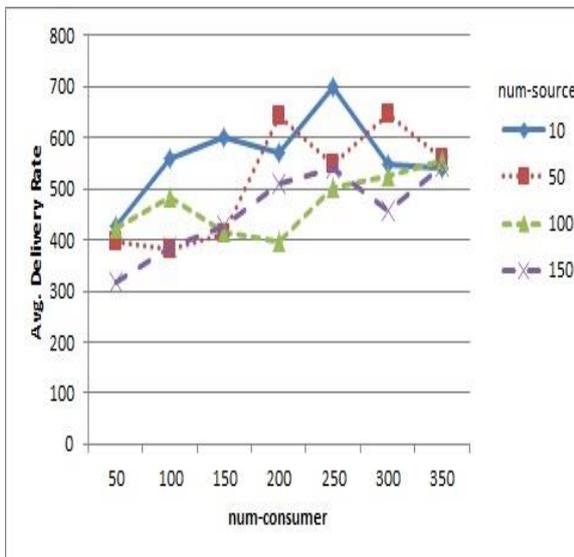
**Figure 12.** The simulation results of Random walk on different networks: Part (a) shows the results of a random walk on the small-world network. The  $x$ -axis shows a number of consumers and the  $y$ -axis shows average end to end delivery rate against a different number of sources. Part (b) shows the results of a random walk for different numbers of consumers and sources on the scale-free network of five hundred nodes. Part (c) shows the results of a random walk on the random network. Part (d) shows random walk results on all networks. Results of all three networks are compared (numbers of consumers: 50, 100, 150, 200, 250, 300, 350, number of sources: 10, 50, 100, 150).



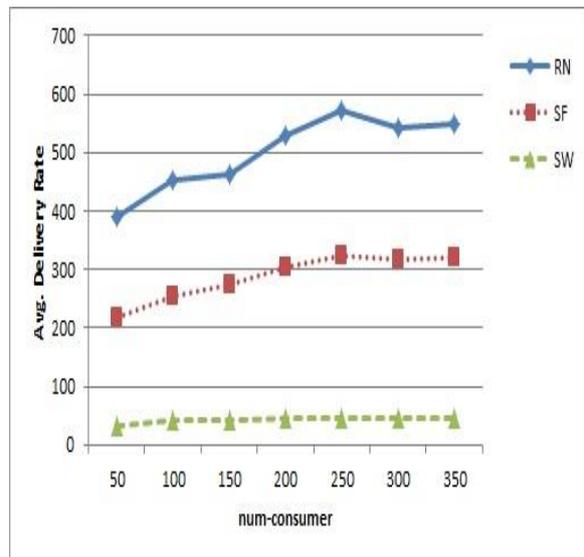
(a) CR-betweenness on Small-world



(b) CR-betweenness Scale-free

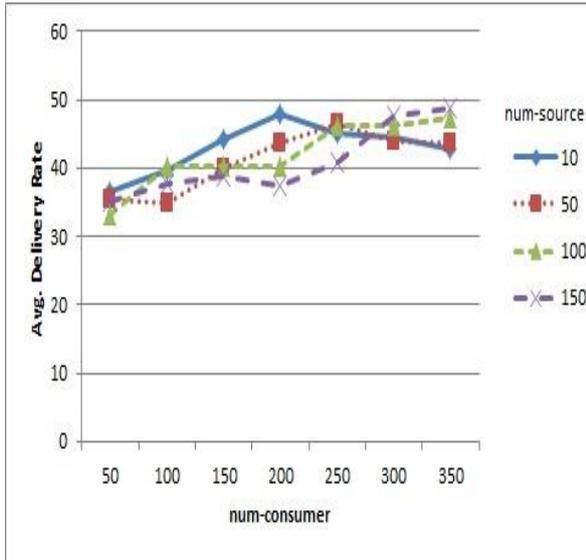


(c) CR-betweenness on Random network

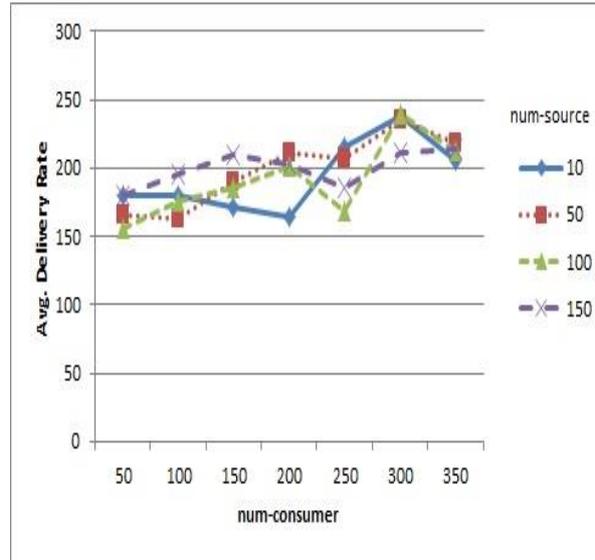


(d) CR-betweenness on all networks

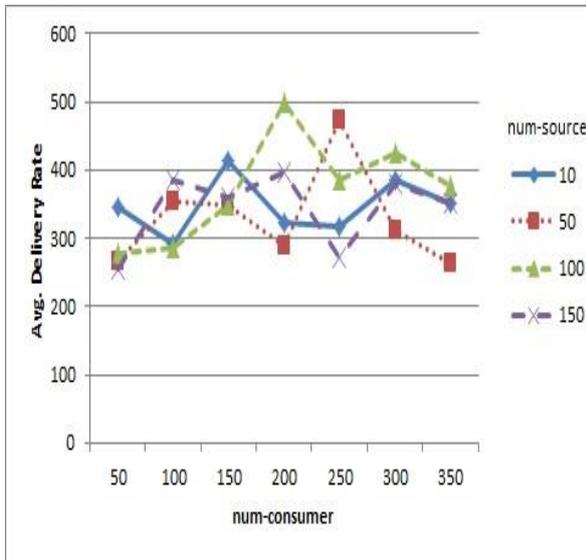
**Figure 13.** The simulation results of betweenness centrality routing on different networks. Each network is composed of 500 nodes. The simulation was carried out on different numbers of sources and consumers (sources: 10, 50, 100, and 150, consumers: 50, 100, 150, 200, 250, 300, and 350). Part (a) shows simulation results on the small-world network. Part (b) shows simulation results on the scale-free network. Part (c) shows simulation results on the random network. Part (d) shows betweenness centrality routing on different networks.



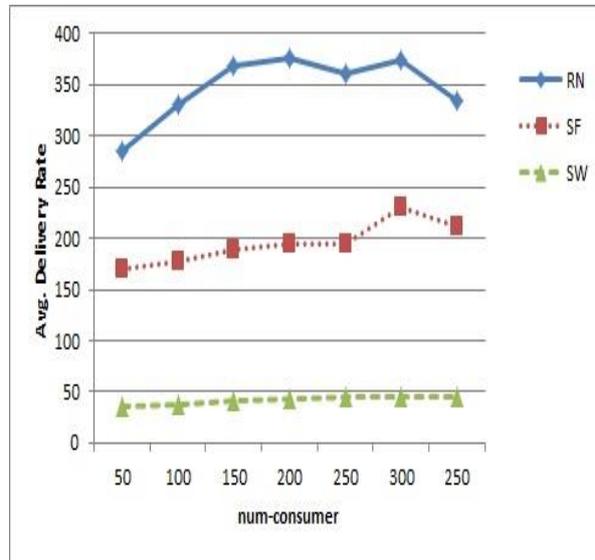
(a) CR-closeness on Small-world



(b) CR- closeness Scale-free

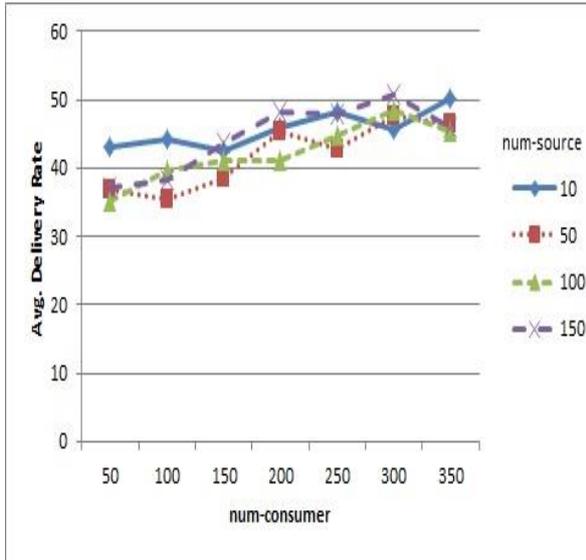


(c) CR- closeness on Random network

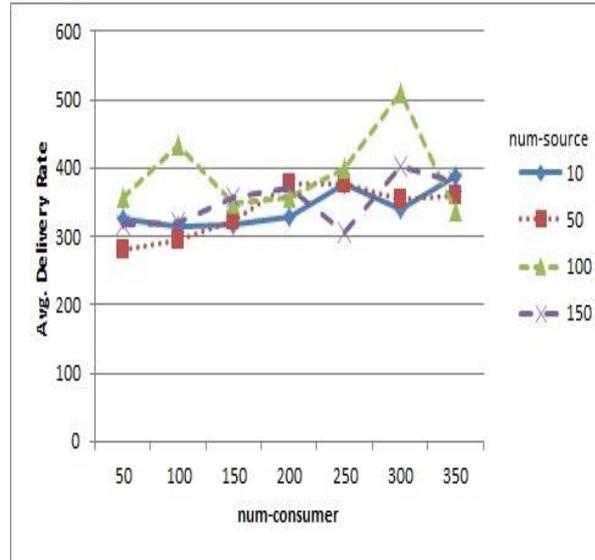


(d) CR- closeness on all networks

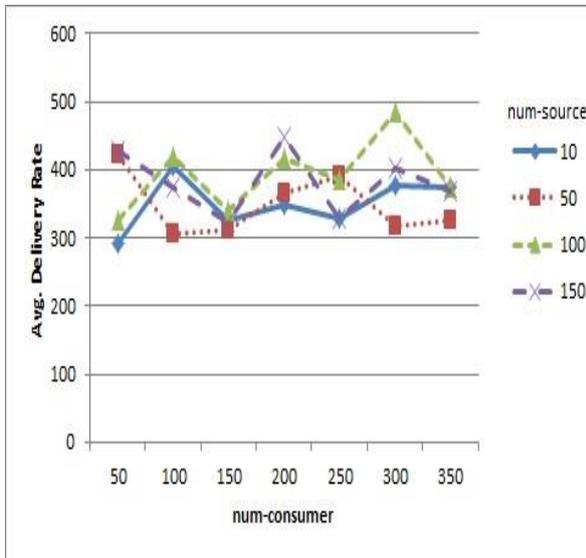
**Figure 14.** The simulation results of closeness centrality routing on different networks. Each network is composed of 500 nodes. The simulation was carried out on different numbers of sources and consumers (sources: 10, 50, 100, and 150, consumers: 50, 100, 150, 200, 250, 300, and 350). Part (a) shows simulation results on the small-world network. Part (b) shows simulation results on the scale-free network. Part (c) shows simulation results on the random network. Part (d) shows closeness centrality routing on different networks.



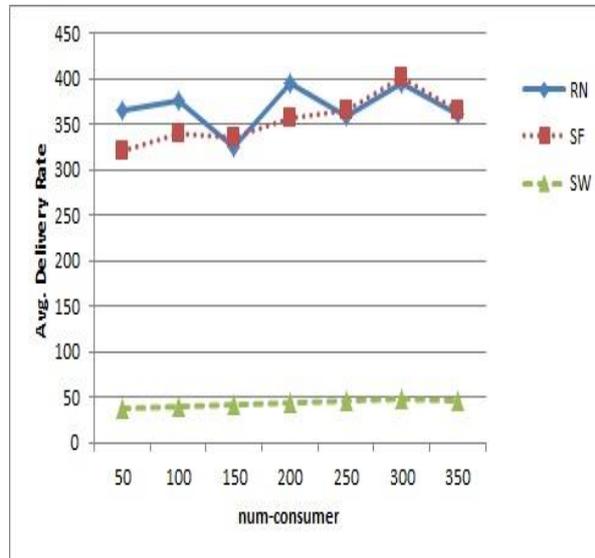
(a) CR-degree on Small-world



(b) CR-degree Scale-free

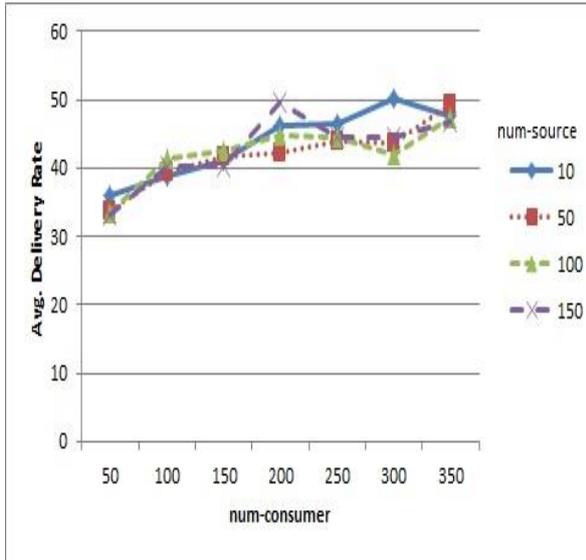


(c) CR-degree on Random network

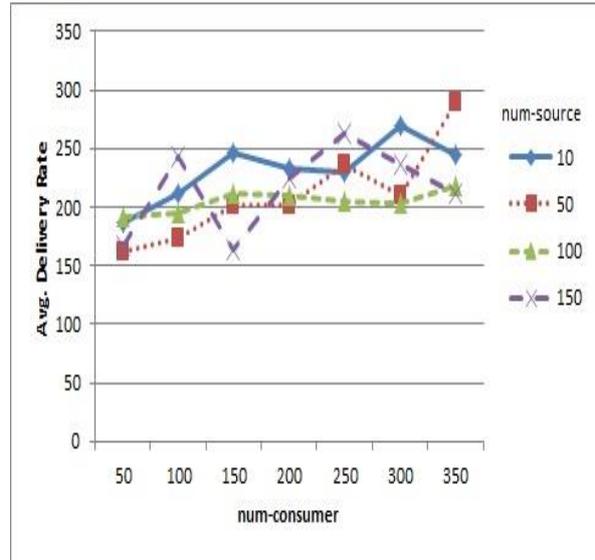


(d) CR-degree on all networks

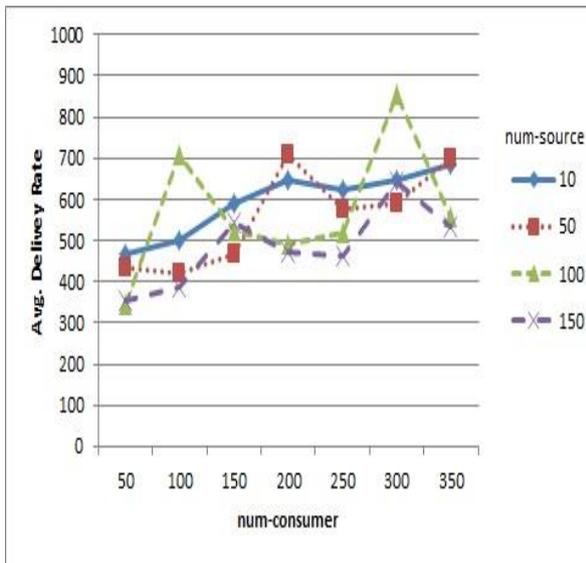
**Figure 15.** The simulation results of degree centrality routing on different networks. Each network is composed of 500 nodes. The simulation was carried out on different numbers of sources and consumers (sources: 10, 50, 100, and 150, consumers: 50, 100, 150, 200, 250, 300, and 350). Part (a) shows simulation results on the small-world network. Part (b) shows simulation results on the scale-free network. Part (c) shows simulation results on the random network. Part (d) shows degree centrality routing on different networks.



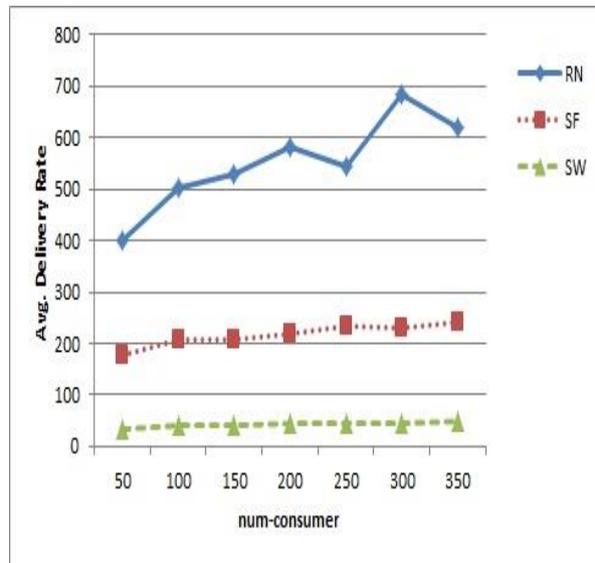
(a) CR-eigenvector on Small-world



(b) CR- eigenvector Scale-free

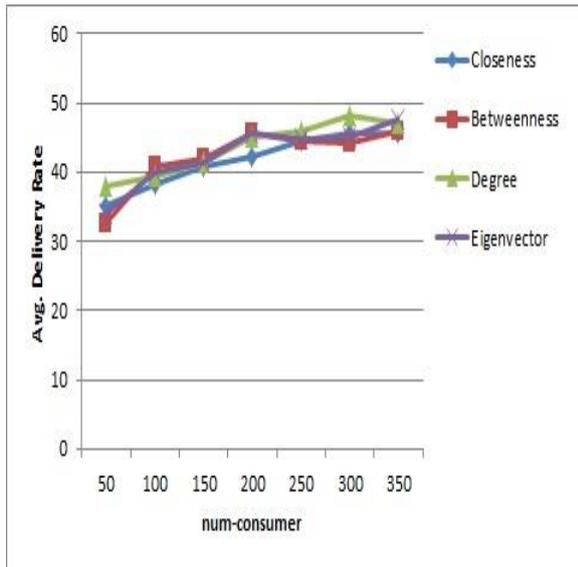


(c) CR- eigenvector on Random network

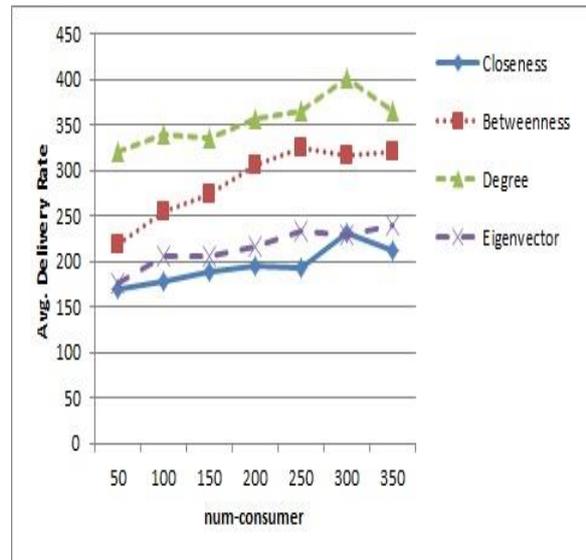


(d) CR- eigenvector on all networks

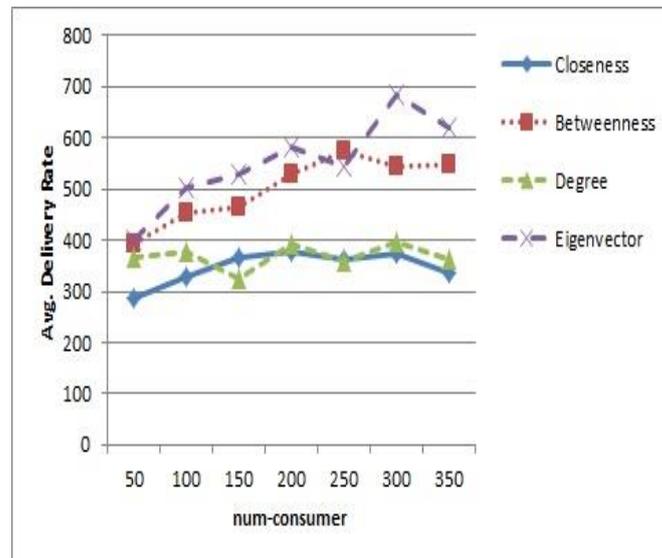
**Figure 16.** The simulation results of eigenvector centrality routing on different networks. Each network is composed of 500 nodes. The simulation was carried out on different numbers of sources and consumers (sources: 10, 50, 100, and 150, consumers: 50, 100, 150, 200, 250, 300, and 350). Part (a) shows simulation results on the small-world network. Part (b) shows simulation results on the scale-free network. Part (c) shows simulation results on the random network. Part (d) shows eigenvector centrality routing on different networks.



(a) Centrality routing on Small-world network

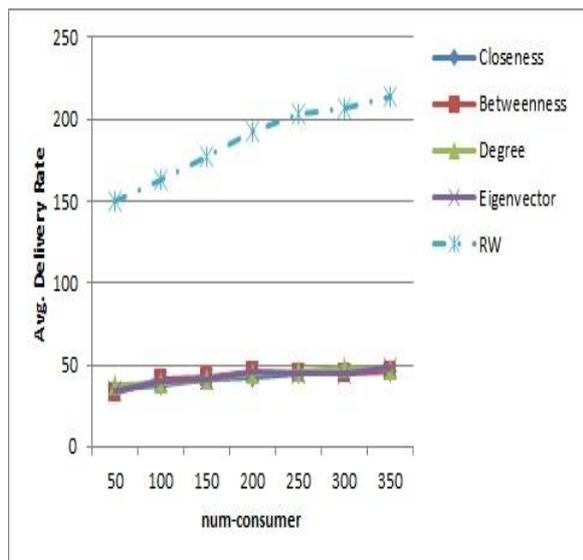


(b) Centrality routing on Scale-free network

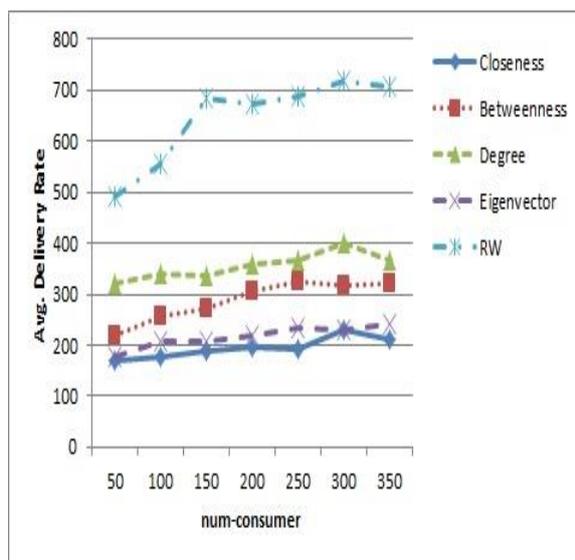


(c) Centrality routing on Random network

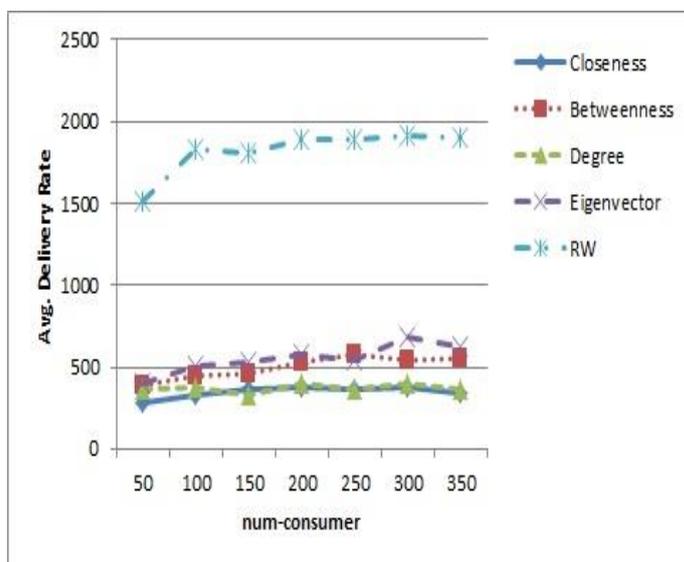
**Figure 17.** The simulation results of centrality-based routing on complex networks. Results for different types of centrality routing based on Closeness, Betweenness, Eigenvector, and Degree are plotted. The experiments were performed for 50, 100, 150, 200, 250, 300, 350 consumers and 10, 50, 100, 150 sources. Part (a) shows centrality-based routing on the small-world network. Part (b) shows centrality-based routing results on the scale-free network. Part (c) shows centrality-based routing on the random network.



(a) CR vs RW routing on Small-world network



(b) CR vs RW routing on Scale-free network



(c) CR vs RW routing on Random network

**Figure 18.** Comparison of random-walk and centrality-based routing algorithms on different networks. Experiments were performed for 50,100,150,200, 250, 300, 350 consumers, and 10, 50, 100, 150 sources. Part (a) shows comparative results of random-walk and centrality-based routing on the scale-free network. Part (b) shows comparative results of random-walk and centrality-based routing on the small-world network. Part (c) shows comparative results of random-walk and centrality-based routing on the random network. The simulation results of centrality routing based on closeness, betweenness, eigenvector, and degree are the same for the small-world network.

**Table 4.** A comparative analysis of previous studies in the smart grid. We analyzed the previous study based on ABM, complex network, specification techniques ODD and DREAM. The comparative study confirms that there is no such specification study for ABM in the smart grid.

Ref.	Objective	ABM	CN	ODD	DREAM
Our study	ABM specification of SG	Yes	Yes	Yes	Yes
[28]	MAS for reactive power management	No	No	No	No
[37]	An adaptive strategy for energy trading	Yes	No	No	No
[30, 31]	Fault location and restoration in the power system network	No	Yes	No	No
[40]	Appliances scheduling in smart home	No	No	No	No
[38]	Communication among large-scale distributed consumers load	No	No	No	No
[39]	Simple power system modeling with consumers and power generators	Yes	No	No	No
[41]	Scheduling of flexible loads	Yes	No	No	No
[42]	Modeling multiple micro grids	Yes	No	No	No
[43]	Battery storage scheduling	Yes	No	No	No
[18]	A conceptual model for smart grid	No	No	Yes	No
[22]	Frequency synchronization in power system	No	Yes	No	No
[23]	Security analysis in power system	No	Yes	No	No

**Table 5.** Model specification follows ODD (continued on p.582).

Category	Sub-category	Our-model
Overview	Purpose	Modeling a smart grid using agent-based and complex network-based approach.
	Entities	Producers, consumers, walkers
	Entities Process	A hybrid centrality-based routing algorithm for an end to end delivery from producers to consumers
Design concept	Basic principle	A cognitive agent-based computing approach is better for modeling and simulation of the large scale power system.
	Emergence	The computation time of the end to end delivery from producers towards consumers
	Adaptation	Based on connected neighbors
	Objective	To measure how much time is taken while moving from one node to the other
	Sensing	Check the state of the neighbor nodes
	Interaction	Local communication
	Stochasticity	Random process
	Observation	Collect data about the number of consumers, number of producers, the number of nodes visited

**Table 5.** Model specification follows ODD (continuation from p.581).

Detail	Initialization	Complex network setup
	Input data	External network setup files
	Sub-model	Parameters:
		<ul style="list-style-type: none"> <li>• number of nodes</li> <li>• number of sources</li> <li>• centrality-based routing</li> <li>• average delivery rate calculation</li> </ul>

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# THE INTENSITY OF HUMAN RESOURCES INFORMATION SYSTEMS USAGE AND ORGANIZATIONAL PERFORMANCE

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## ABSTRACT

Information technologies have become pervasive in various organizational functions. However, their usage impacts organizational performance in various manner, and it depends on the intensity of information technology usage. Human resources information systems (HRIS) are widely used in various organizations. Previous research investigated impact of HRIS to organizational performance, but on the country level and from the adoption perspective. In this work, we focus on the intensity of HRIS usage in organizations and their impact on organizational performance. In order to investigate this relationship, we develop several regression models, using the global dataset with large number of companies worldwide. Research results revealed that the strongest impact to organizational performance is attained through the intensity of HRIS usage, measured by the number of different functionalities available in the software systems. However, this could also be the result of overall development of organizational management and its impact on organizational performance.

## KEY WORDS

information systems, human resource management, human resources information systems, HRIS

## CLASSIFICATION

JEL: J24

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## **INTRODUCTION**

Unpredicted, fast pacing changes of business conditions, force organisations to organize internal organisational environment to quick adaptation and responses with innovative approaches and reduced time to globalised market [1-3]. Under those new business challenges, the human resources management (HRM) function within organisation, having increasingly critical role, it is required to develop instruments to analyse social, economic, political, legal, and technological environment opportunities in order to restructure old HR roles and responsibilities and design new HRM strategies, policies, programmes and processes being the key success factors to the organization's business success [3-5]. In that sense, in the recent past, HRM is facing significant transformations, transiting from the administrative management practices to the position of a strategic partner in developing and supporting organisation's strategy [1, 2, 6].

The fast evolution and extended use of ICT in the field of knowledge management has deeply affected the organisational HRM strategy and its implementation by boosting the transformation of human resources (HR) processes and practices in terms of collecting, storing, using, and sharing information [3, 5, 7].

In the same time, ICT increasingly makes HRM processes to be more efficient and allows their greater involvement in the business strategy, which in return adds significant changes to HRM function [6, 8]. Shifting its focus to knowledge sharing and strategic workforce analysis HRM became an unavoidable contributor to the strategic management of organizations [5, 9].

Therefore, due to the fact that use of ICT strongly impacts the performance of human resources, organizations ever more strongly rely on the use of human resources information management systems as the instrument for realisation of organisational objectives and achieving competitive advantage [5, 10-12].

Although the reasons for adoption of HRIS may vary among the organisations, empirical research shows that three main potential benefits of implementing HRIS in the organisation are; operational efficiency, relational impact changing the nature of the relationship between HR, line managers and employees, and transformational impact changing HRM role in the business environment [13-15].

The goal of the research is to investigate the impact of intensity of HRIS usage on organizational performance using The Cranfield Network on International Human Resource Management (CRANET) survey conducted on a global sample of countries. Several multiple regression models have been developed, with various measures of organizational performance as dependent variables, and with various aspects of HRIS implementation as independent variables. Results indicate the strong relationship between HRIS implementation and organizational performance worldwide. The main contributions of this research are the utilization of CRANET dataset in evaluation of HRIS impact to organizational performance and focus to the intensity of HRIS usage in worldwide organizations, which sheds additional light to the issue of overall relationship of information technologies and organizational competitiveness.

The article is structured as follows. After the introduction, we present the notion of HRIS and discuss its impact on organizational performance from the perspective of pervious research. The methodology is presented, in terms of data, variables and statistical methods used. Main research results are outlined and discuss, and paper finishes with the conclusion section.

## **LITERATURE REVIEW**

The Human Resource Information Systems (HRIS) is described with a large number of various definitions, but none of them is commonly accepted [2]. Majority of definitions

introduce different stages of HRIS development, different approaches to cost and benefits calculation and influence to various human resource management (HRM) functions and relationship [6, 16]. One of numerous definitions considers HRIS as a method of performing organizational HR strategies, policies, and practices by introducing and with full-scale support of information technologies [3, 9, 17].

The concept of HRIS is understood as “the adoption of technology in delivering Human Resource (HR) practices due to the digital revolution in the world is such a tool that organizations can employ to manipulate the performance and behaviour of the people on whom they rely on to achieve business success” [2, 5, 18].

In principle, HRIS represents the integration of HRM and Information and communication technologies (ICT) [4, 19, 20]. Thereby, some researchers regard HRIS as distinctive information system intended to facilitate and support HRM activities such as planning, administration, decision-making, and control [2, 21], while other consider HRIS as a way of executing HRM policies, programmes and transactions in organisations by using information technology [22-24].

Using ICT systems organisations can effectively administer and monitor a large number of HR processes providing in that manner strategically significant information and knowledge, and thus contributing to the achievement of organisation’s competitive advantage [4, 5, 9].

A number of HRIS studies highlight the transformational potential of human resource management within organizations and its strategic significance in modelling superior organisational performance and thus achieving competitive advantage [24, 25]. Consequently, investment in HRIS in terms of organisational objectives enables simplification and cost reduction of HRM activities, enhanced effectiveness of HRM service delivery and transformation of the HRM to a strategic business function [9, 15]. Recent ICT development enables the design of HRIS platform operating in real-time information-based, self-service, and interactive work environment [5, 26].

Among other characteristics, such a platform streamlines and supports HRM operations such as recruitment and employee selection, payroll, and benefits management, education and training administration and monitoring, career-planning, and performance appraisal and management [19, 27, 28]. HRIS also contains features such as employees and managers skill testing, assessment and development, résumé processing, applicant tracking, team and project management, employee involvement and self service management, organizational communication, and, as well, management development [20, 29].

Due to its complexity and costly adoption, an HRIS system requires a detailed need analysis and carefulness in investment decision for organisations of all sizes [1, 11, 30]. Various research studies repeatedly cite that in general, benefits of using HRIS in organisations lead to improved quality of services, enabling timely and fast access to information, and cost reduction related to planning, operating, and controlling HR activities [13, 26, 27].

As a result of their research on usage of HRIS in organisations, Kovach et al. [18] have found some administrative and 28 strategic advantages, while Beckers and Bsat [31], in their study about HRIS, recognized five reasons motivating organisations to adopt HRIS, such as (i) increase competitiveness by improving HR practices, (ii) produce a greater number and variety of HR operations, (iii) shift the focus of HR from the processing of transactions to strategic HRM, (iv) make employees part of HRIS, and (v) reengineer the entire HR function.

Research results present also that organisations are adopting HRIS technology as a platform to enable transformational change, improve the quality of HR processes and practices, allow distributed access to services for both employees and managers and provide improved

support to decision making processes [26, 32]. Several studies distinguish operational, tactical, and strategic dimensions of HRIS, where operational HRIS provides data to support routine and repetitive HR decisions, tactical HRIS provides data for support decisions related with allocation of resources, and strategic HRIS provides data for strategic decisions in human resources planning [27, 28, 33]. In that sense, as some authors have observed, HRIS should enable HRM function to simultaneously perform activities in flexible, strategic, client-focused and cost effective manner, and at the same time, increasing productivity, accelerating response time, improving decision making processes and enhancing client service quality [9, 14, 19].

According to the research of several authors, HRIS is essentially used for business process improvements, development and utilization of talent management processes, evolution of workforce metrics, HR strategy development, workforce management and planning, and competency management [7, 8, 34, 35]. Thereby, an essential quality of modern HRIS platforms is establishing of databases which can produce timely, accurate, appropriate and detailed information, providing the management with an effective decision analysis apparatus and thus enabling them to influence business processes and strategies [6, 19, 30]. As a result, HRIS contributes to the establishing a data driven HRM strategies enabling it to transform its tactical and reactionary role into strategic one [28, 34].

In the recent past, a number of studies have put emphasis on the type of applications predominantly used in HRIS, conditions required for the successful implementation of HRIS, and requirements are supporting successful HRIS [19, 25, 32]. In a sense, some researchers recognize the usage of HRIS as “unsophisticated” one dealing with low level of administrative HR services such as payroll, benefits administration, employee and absence records and “sophisticated” use delivering services in terms of selection and recruitment, training and development, career development, HR planning and performance appraisal [15, 30]. Adoption and implementation of HRIS in the organisation contributes not only to the efficiency and improved quality of HR practices, but can also support transformation of HRM in becoming a strategic partner [28, 34, 36].

Reporting the research results on adoption and use of HRIS, some studies have found that ICT enables the strategic transformation of HRM [24, 32, 37], while other claim that such strategic impact is missing [26, 38, 39]. According to Barrett and Oborn [40] and Arthur and Boyles [14], such arguable findings are coming because of unclear meaning of term “being strategic”.

As recent literature suggests, recent trends in the development of HRM applications are the transformation of traditional HRM or HRIS into internet based HRM (e-HRM) [19, 31, 34]. Thereby, the basic difference between HRIS and e-HRM consists in the fact that HRIS is intended to support for those using services of organisation’s HR function [6, 41], while, in contrary, e-HRM is an internet-based platform available to all the employees at all organisational units [10]. In that respect, HRIS can be considered as a part of e-HRM to the extent it uses internet technologies, where e-HRM is more extensive concept not restricted to persons or processes operating HR function [12, 26, 37]. From another side, the distinction between HRIS and e-HRM can be explained as a transition from the digitalisation of HR processes to digitally arranged and procured data for that processes and functions [20, 35].

Examining the usefulness of HRIS researchers distinguish two extremes; the entirely administrative use of HRIS for daily HR operations and its strategic use for support to decision making processes [31, 32, 37]. It is obvious that both dimensions of HRIS are contributing to the increase of organisation’s performance, where administrative HRIS operations are much more productive when used with ICT support, while in contrary, the possible benefits of strategic HRIS is more demanding to justify and measure because of uncertainty that the benefits can be considered as direct result of strategic deployment of HRIS [12, 35, 38].

There are still missing clear, effective and unambiguous methods for measuring the contribution of HRIS to the organisation value [10, 20, 25]. Among other measures, effectiveness of administrative HRIS can be measured by cost reduction, while, regarding the strategic HRIS, it is difficult to measure HRIS's share in the return on investment (ROI), enhanced employee communications and certain productivity improvements within the HRM function [17, 32, 37].

However, organisations increasingly use the strategic dimension of the HRIS, like one of answers to the competitive pressure [16, 32]. There are studies suggesting that adoption of HRIS corresponds to the effects such as streamlining and simplifying of HR processes, increasing efficiency, faster hiring and decreasing of administrative staff in the HR department [17, 21, 28, 31].

According to the studied literature, it is possible to point out that there is a significant relationship between adoption of HRIS and HRM effectiveness also affecting organisational performance [17, 33, 35].

Some authors give attention on the notion of HRIS as an essential part of any multifaceted organizational information system [20, 25, 36]. They suggest that HRIS is characterised with extensive collaboration between people, structures, strategies, processes, and information, but not depicted exclusively as computerised HR related programmes or tasks [15, 32].

## **METHODOLOGY**

### **DATA**

The Cranfield Network on International Human Resource Management (CRANET) as a network of business schools from about 40 countries, existing since 1989, has been established to collect and analyse data and information on best HR practices and comparative organisational performances in the Europe and globally [42]. With Cranfield School of Management as the network coordinator, CRANET is world leading network of researchers in international HRM, covering all aspects (theoretical and practical) of the HRM domain. Within CRANET, important, representative data on HRM and organisation performance are collected continually, and meticulous scientific analysis is performed providing superior quality results to academic community, interested professionals, different government and international bodies and institutions.

In order to provide data for interested parties, CRANET network conduct on a regular basis, international surveys exploring organisational policies and practices of HRM function internationally. Surveys include specific sets of questions divided into sections about organisation's operations [1].

For the research purpose, the organization is the unit of analysis, and the key respondent is highest manager of HR department, which is aligned with guidelines suggested by Arthur and Boyles [14] regarding identification of key informants for exploring HRM at the organizational level. The questionnaire is developed intentionally to provide factual information about the HRM and HRIS in the organization, not containing questions allowing subjective judgments about the organisation. Among other questions, the questionnaire contains a set of questions examining HRIS use and sophistication. The data collected are intended to represent population in the country regarding the industry and organisation size. The time for collecting the data usually spans an eighteen-month period. The surveys are carried out every three-four years covering about 36 countries with more than 7 000 companies while usual response rate across countries ranges from 5% to 86% [1].

Before each round of conducting the survey, the questionnaires are redesigned in order to satisfy increasing number of participating countries and multicultural aspects of research.

Regarding the respondent organisation size, the threshold has been set to more than 200 employees due to the fact that studies suggest that smaller size organisations incline not to have specialised HRM department. The exception is made for the smaller countries setting the threshold to more than 100 employees [42].

Although the number of participating countries continually grows and processing of collected data becomes more intense and increasingly successful, evidence begins to emerge that such a questionnaire is lengthy and very complex causing decrease in the number of respondents, but also the world economic situation can aggravate conditions for work.

Regarding the nature and mode of operation in CRANET network, each network member collects on its own and processes its own data. It does not prevent cooperation with other countries, but the use of other members' data is subject to the approval of that particular member, whereby no one member can be forced to collaborate. The fact is that cooperation between partners is alive and that network partners share survey data and results developing a body of knowledge on comparative HRM.

In this research, the CRANET Survey Research Instrument has been being used, that contains questions relevant for this survey. Available CRANET dataset is based on the survey conducted globally in 2012 representing relevant sample of corporations. Dataset consists on the sample of 32 countries on all of the continents (Australia, Hungary, South Africa, Austria, Iceland, Sweden, Belgium, Ireland, Switzerland, Bulgaria Israel The Netherlands, Cyprus (including the Turkish Cypriot Community), Japan, Taiwan, Czech Republic, Lithuania, UK, Denmark, Norway, Uruguay, Estonia, Philippines, USA, Finland, Russia, France, Serbia, Germany, Slovakia, Greece, and Slovenia).

However, data is available for 23 countries that sent 37 855 questionnaires and received 3 704 questionnaires, resulting in a response rate of 9,8%. A total number of questionnaires received from 32 countries was 6 258, and that forms a representative sample for the analysis.

## STATISTICAL ANALYSIS

Seven multiple regression models were generated with the following dependent and independent variables, presented in Table 1. Organizational performance is measured with the seven measurements: service quality, level of productivity, profitability, and rate of innovation. Respondents evaluated the organizational performance using the scale from 1 (poor or at the low end of the industry) to 5 (superior).

Independent variables were related to HRIS usage, HRIS type, HRIS outsourcing, HRIS self-service, and employee self-service. In addition, various types of HRIS usage were measured, and the sum of various HRIS usages in companies is used as one of the independent variables.

Company size, market size, market growth, and industry type were used as control variables. Therefore, seven regression models were developed.

**Table 1.** Dependent variables used in regression models. Source: Authors' work, based on CRANET survey.

Variable	Measurement
Dependent	
Service quality (OP1)	(1 – Poor or at the low end of the industry, ... 5 – Superior)
Level of productivity (OP2)	
Profitability (OP3)	
Rate of innovation (OP4)	

**Table 2.** Independent variables used in regression models. Source: Authors' work, based on CRANET survey.

Variable	Measurement
<b>Independent</b>	
HRIS usage (HRIS_USAGE)	0-HRIS is not used in an organization, 1-HRIS is used in an organization
HRIS types (HRIS_TYPE)	HRIS_TYPE_1- A number of separate stand alone HRIS tools, HRIS_TYPE 2- A single, primarily independent HRIS, HRIS_TYPE 3- Primarily interfaced/integrated into a wider management information systems
HRIS Outsourcing (HRIS_Out)	Hris_Out_1-Not outsourced, Hris_Out_2-Outsourced to a small extent, Hris_Out_3-Partly outsourced, Hris_Out_4-Outsourced to a large extent, Hris_Out_5-Completely outsourced
HRIS Manager self-service (HRIS_MSS)	1- Manager self-service (online tools whereby managers can complete HR processes) is used, 0-Not used
HRIS Employee self-service (HRIS_ESS)	1-Employee self-service (online tools whereby employees can access personal information and perform simple HR tasks such as maintaining personal data) is used, 0-Not used
HRA1 – HRA12 – various HRIS purposes	HRA1 Individual personnel records; HRA2 Payroll; HRA3 Benefits; HRA4 Time registration and attendance; HRA5 Recruitment and selection; HRA6 Training and development; HRA7 Performance management; HRA8 Career planning / Succession planning; HRA9 Work scheduling; HRA10 Health and safety; HRA11 Measurement of HR performance (HR metrics); HRA12 Provide HR information, policies and practices
Number of HRIS usages	Sum of variables HRA1 to HRA12

**Table 3.** Control variables used in regression models. Source: Authors' work, based on CRANET survey.

Variable	Measurement
<b>Control</b>	
Size	Micro (< 10 employees); Small (< 50 employees); Medium (< 250 employees); Large (> 250 employees)
Market size	Local; Regional; National; Continent-wide; World-wide
Market growth	Growing; Same; Declining
Industry	The industry type is measured using NACE 2007 classification.

## RESULTS

Table 4. presents the regression analysis summary for the organizational performance as dependent variable according to significance level. All the regression models had rather a low level of R-square, indicating that the variance in dependent variable could be explained by the variance in independent variables with the 4,7% (service quality), 5,8% (level of productivity, 5,4% (profitability) and 6,6% (rate of innovation).

Most of the organizations from the global sample (87,75%) used the HRIS in their day-to-day work. Therefore, it is not surprising that this variable was removed from the sample due to the collinearity. Different types of HRIS also did not have any impact that would be statistically significant, and the same refers to HRIS outsourcing. However, a different

number of HRIS usage had a strong positive statistical impact on all measures of organizational performance, which indicates a clear positive relationship between HRIS usage intensity and organizational performance. HRIS manager self-service did not have a statistically significant impact on any of the measures of organizational performance. However, HRIS Employee self-service did have a strong positive impact to rate of innovation at the 1% level.

**Table 4.** Multiple regression model of HRIS impact to organizational performance (regression coefficients; adjusted R-square). Source: Author's work based on CRANET survey.

Variable group	Variable modalities	Dependent variables			
		OP1	OP2	OP3	OP4
Independent variables					
HRIS usage		<i>a</i>	<i>a</i>	<i>a</i>	<i>a</i>
HRIS types	HRIST_TYPE_2	-0,005	-0,046	0,015	-0,003
	HRIST_TYPE_3	-0,014	-0,019	-0,022	-0,028
HRIS outsourcing	Hris_Out_2	-0,015	-0,010	0,070	-0,013
	Hris_Out_3	-0,070	-0,038	0,020	-0,015
	Hris_Out_4	0,002	-0,027	0,019	0,024
	Hris_Out_5	0,022	0,039	0,045	-0,002
Number of HRIS usages		0,023***	0,041***	0,030***	0,038***
HRIS Manager self-service		0,043	0,022	0,026	0,031
HRIS Employee self-service		-0,031	-0,007	0,021	0,085**
Control variables					
Size	Small (< 50 emp.)	-0,300	-0,228	-0,267	-0,761***
	Medium (< 250 emp.)	-0,344	-0,229	-0,089	-0,628***
	Large (> 250 emp.)	0,351	-0,272	0,004	0,586**
Market size	Regional	-0,115	-0,182***	-0,044	-0,128
	National	0,206***	0,234***	0,122**	0,157***
	Continent-wide	0,215***	0,299***	0,134	0,221***
	World-wide	0,261***	0,369***	0,323***	0,378***
Market growth	Same	0,021	0,065	0,134***	0,096**
	Declining	-0,177***	-0,216***	-0,272***	-0,276***
Industry	B. Energy and water	-0,008	-0,002	-0,054	0,034
	C. Chemical products	-0,076	0,015	-0,145	-0,061
	D. Metal manuf.	-0,127	-0,002	-0,147	0,207
	E. Other manuf.	0,024	0,085	-0,128	0,271
	F. Building	0,096	0,154	0,052	0,167
	G. Retail and distribution...	0,043	-0,009	-0,096	0,087
	H. Transport & Communication...	-0,017	0,026	-0,175	0,080
	I. Banking; finance; services	0,115	0,106	0,041	0,116
	J. Personal, domestic...	0,075	0,302	0,373	0,487**
	K. Health services	0,115	0,111	-0,110	0,392**
	L. Other services ...	0,046	0,092	-0,177	0,360**
	M. Education...	0,106	0,305**	-0,220	0,418***
	N. Social Services	0,123	0,210	-0,106	0,315*
	O. Public administration	-0,065	0,131	-0,381**	0,134
Other	0,132	0,249**	0,038	0,378***	
Constant		3,811***	3,196***	3,012	3,202***
Adjusted R-square		0,047	0,058	0,054	0,066

\*\*\*statistically significant at 1 %

\*\*statistically significant at 5 %

\*statistically significant at 10 %

*a* – omitted because of collinearity

Overall, the rate of innovation was higher for the large companies, but small and medium size had a negative impact on rate of innovation. Regional market size overall had a negative impact on the rate of productivity, while national, continental and world-wide markets had a positive impact on all measures of organizational performance. Declining markets had overall negative impact on organizational performance, while at least same level of market growth had positive impact on productivity and rate of innovation. Impact of various industries was different from organizational performance, but it is interesting that companies operating in tertiary sector (industries J, K, L, M) had overall higher rate of innovation.

## **CONCLUSION**

The main purpose of this research was to contribute to the better utilization of HRIS usage in organizations. The research outcomes may also help in improving the approaches used in HRIS usage in organizations, with the goal to maximize its impact on organizational performance. A part of the main objective was achieved through study of the available literature on ICT, HRM and particularly on HRIS. By exploring sources was possible to define the critical factors that influence both HRIS and overall organizational performance, determine substantial differences of HRIS impact to organizations according to HRIS type and number of areas in which HRIS is implemented, availability of self-service, and consequences and impact of outsourcing.

We have conducted a regression analysis, using CRANET database, with goal to investigate the impact of HRIS usage intensity on organizational performance. Four measurements of organizational performance were used: perception of the service quality, level of productivity, profitability, and rate of innovation. Different aspects of HRIS usage were taken into account, and the following variables had a statistically significant impact to the organizational performance: HRIS usage intensity measured by the number of HR usage functions available in HRIS, such as Individual personnel records, Payroll, Benefits, Time registration and attendance, Recruitment and selection, Training and development, Performance management, Career planning / Succession planning, Work scheduling, Health and safety, Measurement of HR performance (HR metrics), and Provide HR information, policies and practices. It seems that companies that have HRIS with more HR functions are overall more productive, innovative and produce better service quality, which results in overall higher profitability. This could also indicate that companies are becoming more efficient in transferring their HR practices through the information system, which is more evident for larger companies, operating on larger markets, which are growing or at least stagnating. Therefore, companies can make better efforts in incorporating more of their HR practices in HRIS. This result could also be useful to companies that develop HRIS so that they can cooperate more intensively with the users of their systems in order to better reflect their HR practices in information systems. However, it is also possible that the usage of HRIS incites companies to enhance their HR practices, which should be investigated in future research, with qualitative methodologies, such as longitudinal case studies of companies with modest HR practice which adopted HRIS with more developed HR functions. It would be worthwhile to investigate, in addition, which factors support the companies to use all the options available in HRIS and to maximise its positive impact to organizational performance.

This research has several limitations that stem mainly from the limitations of CRANET database and structure of the survey questions. Therefore, our results could be tested in future research using different research instruments and different research approaches, such as longitudinal case study research.

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# TOWARDS A QUANTITATIVE MODEL OF EPIDEMICS DURING CONFLICTS

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## ABSTRACT

Epidemics may contribute to and arise as a result of conflict. The effects of conflict on infectious diseases are complex. There have been counter-intuitive observations of both increase and decrease in disease outbreaks during and after conflicts. However there is no unified mathematical model that explains all these observations. There is an urgent need for a quantitative framework for modelling conflicts and epidemics. The article introduces a set of mathematical models to understand the role of conflicts in epidemics. The corresponding mathematical framework has the potential to explain the counter-intuitive observations and the complex role of human conflicts in epidemics. This work suggests that aid and peacekeeping organizations should take an integrated approach that combines public health measures, socio-economic development, and peacekeeping in conflict zones.

This approach exemplifies the role of non-linear thinking in complex systems like human societies. The work presented should be looked upon as a first step towards a quantitative model of disease spread in conflicts.

## KEY WORDS

simulation models, epidemics, conflicts

## CLASSIFICATION

JEL: C65

PACS: 87.19.Xx, 89.90.+n

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## INTRODUCTION

Epidemics and conflicts are closely connected. Epidemics may both contribute to conflict and also arise as a result of violence in human societies. The effects of conflict on infectious diseases are multi-faceted and complex. There have been counter-intuitive observations of both increase and decrease in disease outbreaks during and after conflicts [1]. For example, epidemics have been observed to be both initiated and diminished by conflicts. Paradoxically, epidemics have been observed to rebound, even after conflicts have ended. However there is no unified quantitative model that explains all these counter-intuitive observations.

There is an urgent need for a quantitative framework for modelling conflicts and epidemics. The recent appearance of emerging pathogens like Zika and Ebola virus in conflict-prone regions highlights the need for a quantitative framework that combines the effects of both disease spread and conflicts.

Such models can be a first step towards shaping public health policy, spreading public awareness and may also be a tool for public health professionals in conflict zones.

Quantitative techniques like these may also help predict possible emerging hotspots for emerging diseases [2]. Models of joint epidemic and conflict risk may be of considerable interest to future humanitarian and peacekeeping missions.

## MODELS

We start with a basic susceptible-infected-recovered (SIR) model. The density of susceptible people who are healthy but can be infected by a pathogen is denoted by  $S$ . The density of people who are infected is represented by the compartment  $I$ . The interaction between infected and susceptible causes more infections which is represented by the mass action term  $-\beta IS$  (the rate at which susceptibles become infected). This shows up as influx term in the infected compartment ( $+\beta IS$ ). The density of people who recover from infections is represented by  $R$ . This is composed of an influx from the infected population at a rate of  $\nu I$ . The model is shown below.

$$\frac{dS}{dt} = -\beta IS, \quad (1)$$

$$\frac{dI}{dt} = \beta IS - \nu I, \quad (2)$$

$$\frac{dR}{dt} = \nu I. \quad (3)$$

We assume in this simple model that those who recover never become infected again. Additionally, we neglect birth and death processes in this simple model. All these assumptions can be relaxed in more complex models. A simulation of this simple model is shown further in Figure 1.

The basic reproductive number ( $R_0$ ) is the expected number of new infections produced by a single infected individual over the individual's productively infected lifespan (in a completely susceptible population). It is given by the following quantity

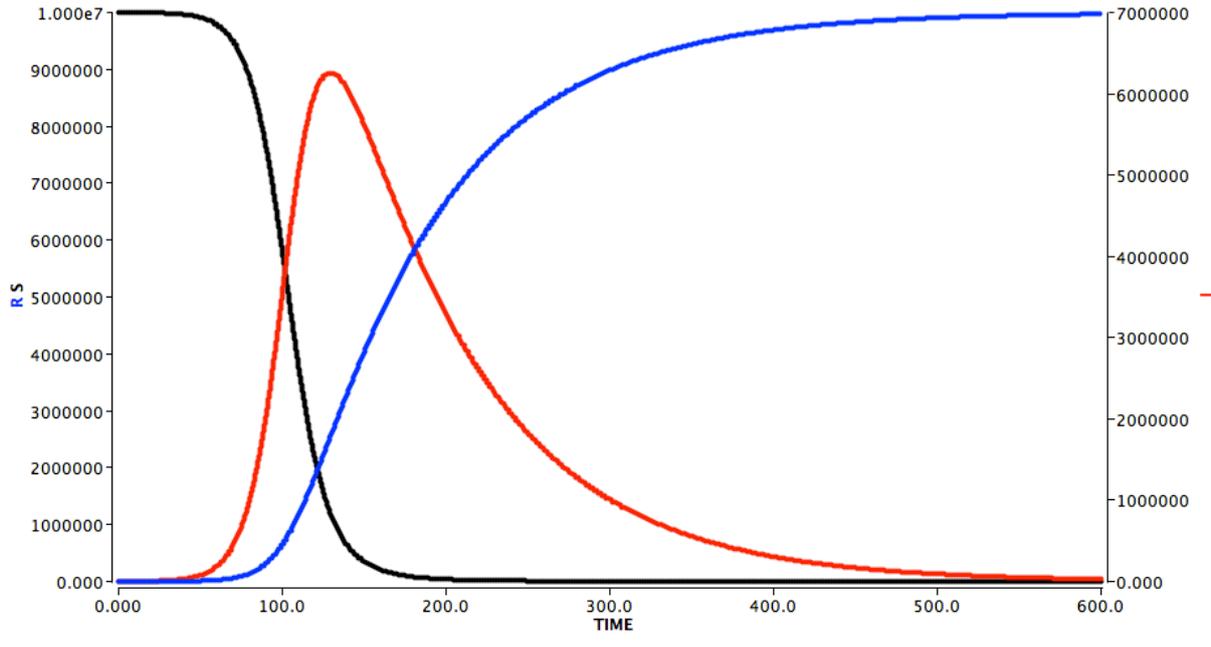
$$R_0 = \frac{\beta S}{\nu}. \quad (4)$$

This can be derived by observing that the infection can be sustained if the rate of change of infected individuals ( $I$ ) is greater than 0:

$$\frac{dI}{dt} = \beta IS - \nu I > 0 \Rightarrow \beta IS > \nu I. \quad (5)$$

This finally gives us the following relationship

$$R_0 = \frac{\beta S}{\nu} > 1. \quad (6)$$



**Figure 1.** A simulation of the basic SIR model showing how the density of infected people ( $I$ , in red) rises and then decreases. The density of susceptible people ( $S$ , in black) declines causing the infection to start declining. The density of people who recover ( $R$ , in blue) increases throughout the process.

## METHODS

The dynamical models were implemented in Berkeley Madonna [3] and have been made available online [4].

## RESULTS

### COUPLED MODELS OF DISEASE AND CONFLICT

We introduce the following model of two populations in conflict with each other.  $S_1$  and  $S_2$  refer to susceptible populations of two nations or communities within a nation (combines both civilians and combatants). The first term in each of these compartments simulates removal due to infection. The second term models influx or efflux of people: this could be due to refugees fleeing from one country to another or the invasion of an army. This is modelled as a piecewise linear function ( $X$ ).

$$\frac{dS_1}{dt} = -\beta I S_1 + \alpha_1 X, \quad (7)$$

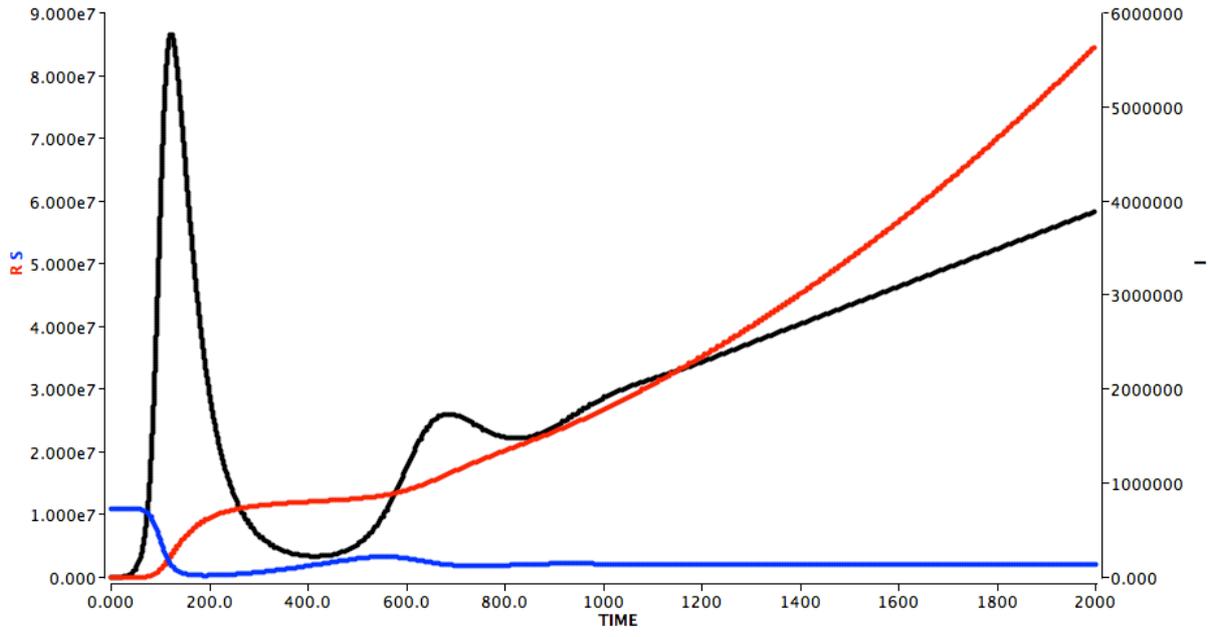
$$\frac{dS_2}{dt} = -\beta I S_2 + \alpha_2 X, \quad (8)$$

$$\frac{dI}{dt} = \beta I S_1 + \beta I S_2 - \nu I, \quad (9)$$

$$\frac{dR}{dt} = \nu I. \quad (10)$$

$$X = \begin{cases} 0, & t < t_i, \\ \delta \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (11)$$

We note that some of these parameters might be correlated, e.g. increased migration might breakdown already strained medical services (parameter  $\nu$  in the SIR model). We look at this in a later model.



**Figure 2.** A simulation of the basic two-nation model showing how the density of infected people ( $I$ , in black) rises, decreases and then increases again. The density of susceptible people ( $S$ , in blue) declines initially causing the infection to start declining. It then starts increasing due to influx of soldiers and refugees, causing the rebound in infections. The density of people who recover ( $R$ , in red) increases throughout the process.

We only show representative plots to demonstrate this case. We note that this model is not specific to any disease nor do we estimate model parameters specific to any pathogen.

Our objective is only to demonstrate that such a situation is indeed feasible. It would be possible to fit these mathematical models to data, should adequate data become available.

### AN EPIDEMIC CAN BE DECREASED DURING TIMES OF CONFLICT

Epidemics could be reduced for some time during conflicts. This could happen due to:

- a) mobility of people being reduced. For example, lower incidence of HIV has been reported in Angola and is attributed to reduced mobility due to conflicts [1].
- b) increase in susceptible population during conflict due to increase in migration.

We show this effect can be simulated by an increase in the value of  $S(t)$  after some time. The increase ( $X$ ) is modelled as a piecewise linear function: it is 0 before some time and increases linearly after some time. The model is shown below.

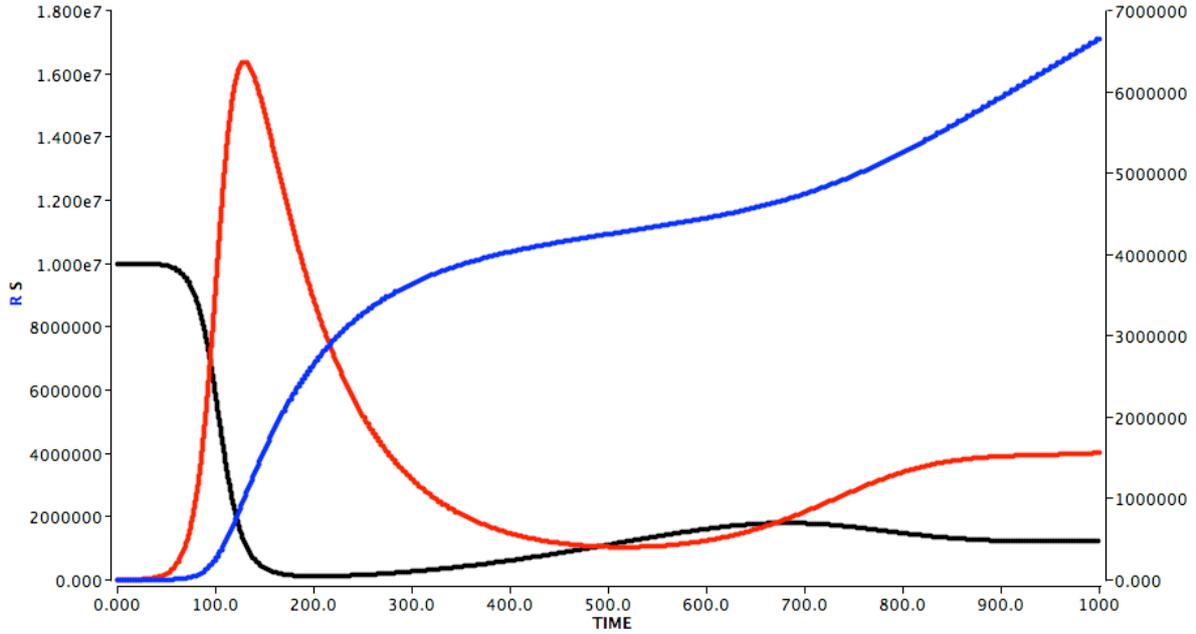
$$\frac{ds}{dt} = -\beta IS + \alpha X, \tag{12}$$

$$\frac{dl}{dt} = \beta IS - \nu l, \tag{13}$$

$$\frac{dR}{dt} = \nu l. \tag{14}$$

$$X = \begin{cases} 0, & t < t_i, \\ \delta \cdot (t - t_i), & t \geq t_i. \end{cases} \tag{15}$$

A simulation of this outcome is shown in Figure 3 and it can be seen that the density of infections declines (after 100 time units) and then comes back up again.



**Figure 3.** A simulation of the migration model showing how the density of infected people ( $I$ , in red) rises and then decreases. The density of susceptible people ( $S$ , in blue) declines initially causing the infection to start declining. It then starts increasing due to migration, causing the rebound in infections. The density of people who recover ( $R$ , in red) increases throughout the process.

### EPIDEMICS COULD REAPPEAR OR BE DIMINISHED AFTER THE END OF CONFLICTS

Epidemics could reappear after the end of conflicts due to migration of refugees displaced during the conflict. This highlights the need for sustained humanitarian aid missions even after conflicts have ceased.

This effect can be simulated by an increase in  $S(t)$ . The model has been introduced in the previous section. Figure 3 shows that the infection can decline over certain periods of time; in the simulation it declines between 100 and 500 time units, before rebounding again.

After a conflict ends, there could also be migration of refugees and peacekeepers, all of whom could either add to the susceptible or infected pool. This could cause a resurgence of the epidemic. We show another plausible model for this below. This model has an influx (after a certain time) in the susceptible ( $S$ ) and infected ( $I$ ) compartments. The increase is modelled as a piecewise linear function.

$$\frac{dS}{dt} = -\beta IS + \alpha_1 X_1, \quad (16)$$

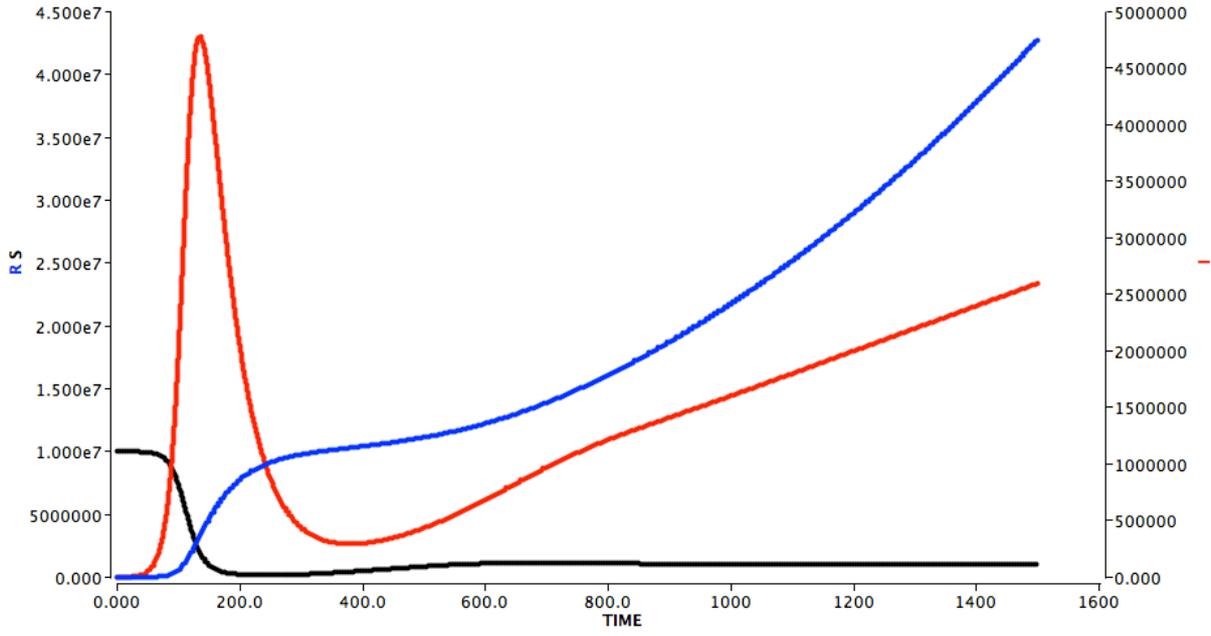
$$\frac{dI}{dt} = \beta IS - \nu I + \alpha_2 X_2, \quad (18)$$

$$\frac{dR}{dt} = \nu I. \quad (19)$$

$$X_1 = \begin{cases} 0, & t < t_i, \\ \delta_1 \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (20)$$

$$X_2 = \begin{cases} 0, & t < t_i, \\ \delta_2 \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (21)$$

Results of a simulation are shown in Figure 4. The plot shows how the density of infected people rises, then decreases and then increases again.



**Figure 4.** A simulation of a model after a conflict with migration of refugees and peacekeepers in both the infected and susceptible populations. The simulation shows how the density of infected people ( $I$ , in red) rises, then decreases and then increases again. The density of susceptible people ( $S$ , in black) declines and then increases again after a conflict (due to migration of refugees and peacekeepers). The density of people who recover ( $R$ , in blue) increases throughout the duration of the simulation.

### THE EFFECTS OF MIGRATION ON DISEASES

As the previous cases demonstrate, migration has a significant effect on disease spread, during and after conflicts. Here we examine in more detail the different effects migration can have on spread of infectious diseases. Other additional factors that can compound recovery from epidemics, caused in part by both migration and conflicts, are:

- a) breakdown of medical infrastructure,
- b) over-crowding, and,
- c) unsanitary facilities.

Most of these would affect the rate of recovery (parameter  $\nu$ ) in the model. We can simulate these effects by lowering the value of  $\nu$  in the model. The rate of recovery ( $\nu$ ) is at baseline before some time and then is assumed to decrease linearly with time. We can look at other functional forms, but this is a very basic and simple formulation. In the future we can fit more complex functions, when data becomes available.

The model is as follows:

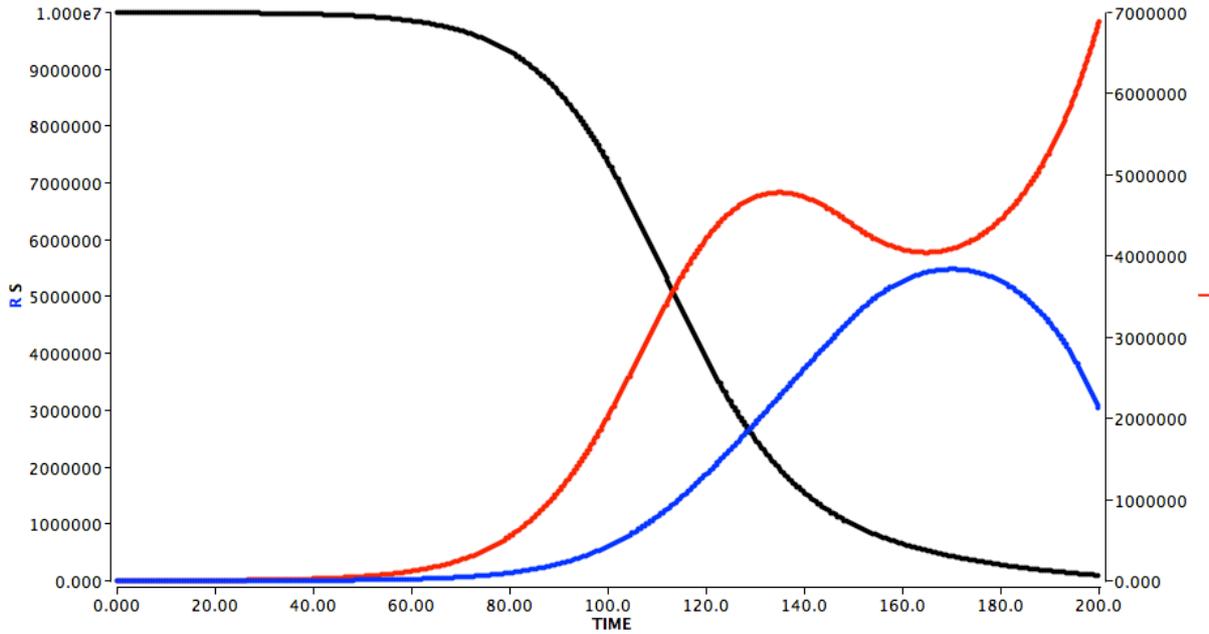
$$\frac{dS}{dt} = -\beta IS, \quad (22)$$

$$\frac{dI}{dt} = \beta IS - \nu I, \quad (23)$$

$$\frac{dR}{dt} = \nu I. \quad (24)$$

$$\nu = \begin{cases} \nu_0, & t < t_i, \\ \nu_0 - \eta \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (25)$$

A simulation of this outcome is shown in Figure 5.



**Figure 5.** A simulation of the migration model with additional factors showing how the density of infected people ( $I$ , in red) rises, then decreases and then increases again. The density of susceptible people ( $S$ , in black) declines throughout this process. The density of people who recover ( $R$ , in blue) increases and then decreases again due to the decline in the rate of recovery (due to breakdown in infrastructure).

Migration has a significant effect on infectious diseases, both during and after conflicts. It may make more people susceptible to diseases, or isolate people from diseases in regions with poor connectivity. In future work, we will look at spatial models that couple migration, disease and conflicts.

### SCENARIO WITH MULTIPLE FACTORS

We acknowledge the complexity of looking at conflict, disease and socio-economics as a coupled system. Many of the factors that we outlined above may co-occur with each other. As an example, we present one such integrated model below. The model below incorporates an increase in the susceptible population  $S(t)$ . It also simulates a breakdown of critical infrastructure that causes a decline in the recovery rate ( $v$ ).

$$\frac{dS}{dt} = -\beta IS, \quad (26)$$

$$\frac{dI}{dt} = \beta IS - vI, \quad (27)$$

$$\frac{dR}{dt} = vI. \quad (28)$$

$$v = \begin{cases} v_0, & t < t_i, \\ v_0 - \eta \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (29)$$

$$X = \begin{cases} 0, & t < t_i, \\ \delta \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (30)$$

### MODELLING INTERVENTIONS

If there is available data, future modellers can even try to estimate the increase in recovery rate ( $v$ ) required to reduce epidemics below a certain threshold. This assumes that the intervention can only effect  $v$ . Other interventions can affect the susceptible ( $S$ ) and infected ( $I$ ) populations by targeted vaccinations.

Such a model is given in this section. Currently, there are no data to calibrate these models. It is hope that emerging technologies like smartphones in developing nations and remote sensing by satellites can enable modellers to get some approximate estimates of model parameters, like populations of infected and susceptible people [5]. This may enable forecasts of amount of humanitarian aid required to reduce an infection below a threshold. We model an intervention as an increase (piecewise linear) in the rate of recovery of infected individuals  $\nu$ .

$$\frac{dS}{dt} = -\beta IS, \tag{31}$$

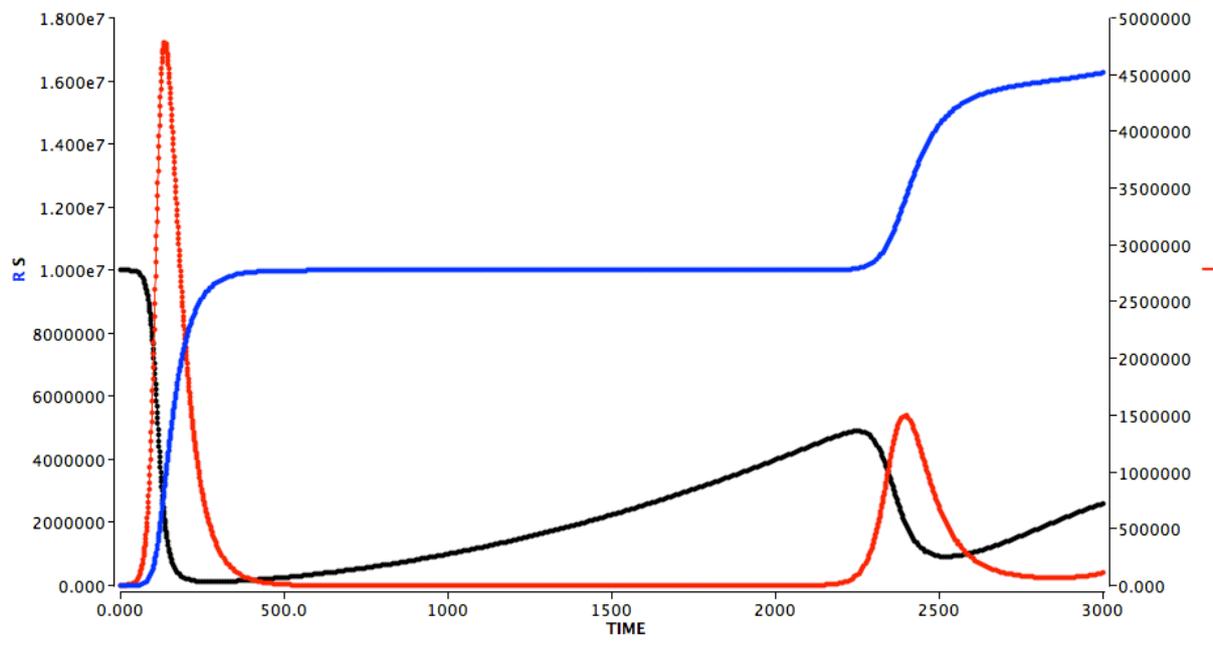
$$\frac{dI}{dt} = \beta IS - \nu I, \tag{32}$$

$$\frac{dR}{dt} = \nu I. \tag{33}$$

$$\nu = \begin{cases} \nu_0, & t < t_i, \\ \nu_0 + \eta \cdot (t - t_i), & t \geq t_i. \end{cases} \tag{34}$$

$$X = \begin{cases} 0, & t < t_i, \\ \delta \cdot (t - t_i), & t \geq t_i. \end{cases} \tag{35}$$

First, we show the simulations from a model without the intervention, Figure 6.

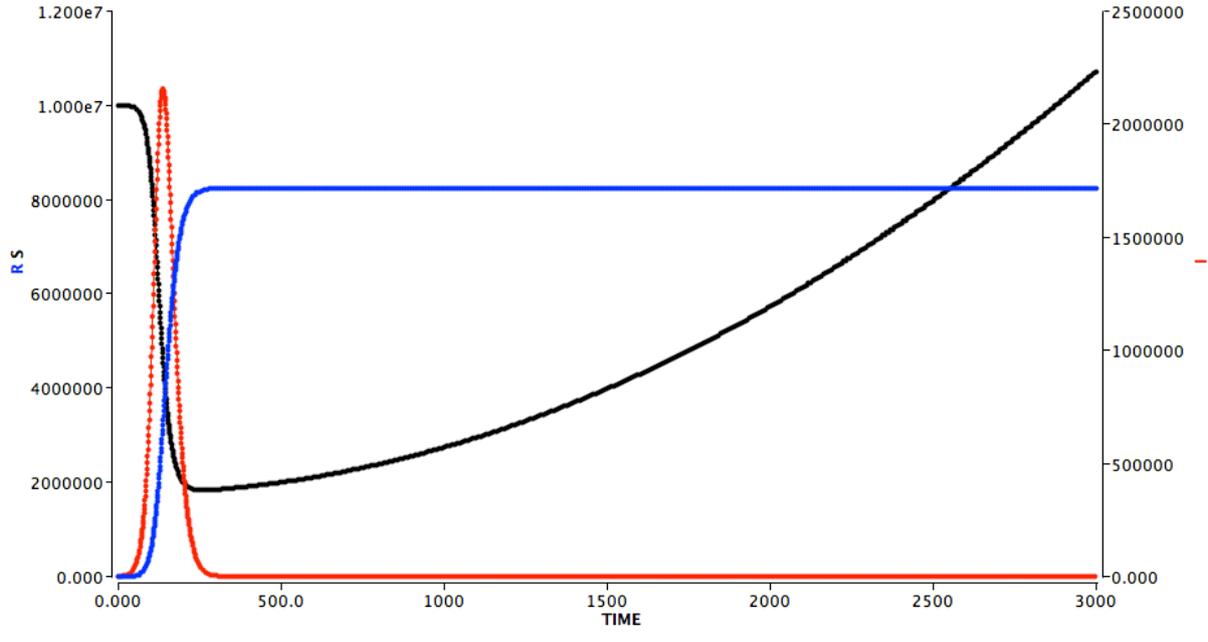


**Figure 6.** A simulation of the migration model showing how the density of infected people ( $I$ , in red) rises, then decreases and then increases again (due to migration). The density of susceptible people ( $S$ , in black) declines and then increases due to migration.

We then show the effect of an intervention of increasing the rate of recovery ( $\nu$ ) by improved access to health services and vaccination, Figure 7). The intervention, initiated after some time, has the effect of checking the rebound in infections seen in the model without interventions.

### EFFECT OF POVERTY ON DISEASES

We can simulate the effect of poverty on disease propagation by coupled models of socio-economics and diseases. The gross domestic product (GDP) of a country may affect the rate at which infected patients recover (parameter  $\nu$ ). Poorer nations may have a lower value of  $\nu$  thereby compromising their chances of recovering from epidemics after a conflict. We parameterize  $\nu$  as a function of GDP.



**Figure 7.** A simulation of the migration model with an intervention of increasing the rate of recovery after some time ( $v$ ). This has the effect of checking the increase in infected people seen in the model without intervention. The density of infected people ( $I$ , in red) rises and then decreases.

The corresponding model is as follows:

$$\frac{dS}{dt} = -\beta IS, \quad (36)$$

$$\frac{dI}{dt} = \beta IS - vI, \quad (37)$$

$$\frac{dR}{dt} = vI. \quad (38)$$

$$v = \begin{cases} f(GDP), & t < t_i, \\ f(GDP) - \eta(GDP) \cdot (t - t_i), & t \geq t_i. \end{cases} \quad (39)$$

## SOCIO-ECONOMICS OF DISEASE SPREAD

Conflicts can contribute to and also may be caused by diseases [6]. Here we consider the socio-economics of infectious disease spread.

Diseases can breakdown resources, reduce GDP, and deplete resources. This may in some instances compel these nations to initiate conflicts for acquiring resources externally [6].

We look at coupled models of socio-economics and disease spread. We assume that the rate of recovery ( $v$ ) from infections is related to the GDP.

The model is shown further in the text. We assume there are two countries that are competing with each other economically. Their GDPs are denoted by  $x$  and  $y$ . They each have epidemics where the rate of recovery ( $v$ ) is dependent on GDP.

$$\frac{dx}{dt} = \alpha x - \sigma xy, \quad (40)$$

$$\frac{dy}{dt} = -\delta y + \gamma xy, \quad (41)$$

$$\frac{dS_j}{dt} = -\beta I_j S_j, \quad (42)$$

$$\frac{dI_j}{dt} = \beta I_j S_j - \nu_j I_j, \quad (43)$$

$$\frac{dR_j}{dt} = \nu_j I_j, \quad (44)$$

$$\nu_1 = f(y), \nu_2 = f(x). \quad (45)$$

with  $j = 1, 2$  in (42)-(44). This is a very simple model where two countries that are competing economically have GDPs  $x$  and  $y$ . The rate of recovery ( $\nu$ ) is dependent on GDP through a function  $f(GDP)$ .

In this model, the GDP fluctuates over time due to competition between the two countries (as in a predator-prey model). The rate of recovery from infections also changes due to linked dynamics with socio-economics (GDP).

Formulated demonstrate the vicious cycle of poverty, disease and conflicts especially in some developing nations. This also suggests that aid organizations should take an integrated public health approach that is combined with efforts to aid socio-economic development.

We also show another model where we model the public health burden of epidemics.

$$\frac{dx}{dt} = \alpha x - \sigma xy, \quad (46)$$

$$\frac{dy}{dt} = -\delta y + \gamma xy, \quad (47)$$

$$\frac{dS_j}{dt} = -\beta I_j S_j, \quad (48)$$

$$\frac{dI_j}{dt} = \beta I_j S_j - \nu_j I_j, \quad (49)$$

$$\frac{dR_j}{dt} = \nu_j I_j, \quad (50)$$

$$\nu_1 = f(y), \nu_2 = f(x). \quad (51)$$

Again we assume a scenario where two countries are competing economically and have GDPs  $x$  and  $y$ . As before the rate of recovery ( $\nu$ ) is dependent on GDP through a function  $f(GDP)$ . Additionally, the GDPs of the countries are now also reduced based on a function ( $g$ ) of the number of infected people. This models the economic impact of epidemics.

## A SCENARIO OF A COMPLEX INTERACTION OF DISEASE SPREAD IN A PREDATOR-PREY SYSTEM

Our models are general enough to capture conflict-disease dynamics in other species. We consider a final scenario which may occur in other species. Consider two species, one of which preys on the other (predator-prey system). Assume that there is an infectious disease that infects only one species (say, the prey).

The model is as follows:

$$\frac{dx}{dt} = \alpha x - \sigma xy, \quad (52)$$

$$\frac{dy}{dt} = -\delta y + \gamma xy, \quad (53)$$

$$Y = S + I + R, \quad (54)$$

$$\frac{dS}{dt} = -\beta IS, \quad (55)$$

$$\frac{dI}{dt} = \beta IS - \nu I, \quad (56)$$

$$\frac{dR}{dt} = \nu I, \quad (57)$$

Here we have a predatory-prey Lotka-Volterra model coupled to an SIR model. Whenever the density of predator ( $x$ ) goes down, the prey ( $y$ ) goes up. The total population of the prey

(y) is composed of  $S + I + R$ . Some fraction of  $S$  is going to increase whenever the population of prey increases.

From the discussion in the previous sections, when we increase the susceptible population, we can get oscillations of infections going up and down. We hypothesize that in certain cases the pathogen may evolve to reproduce around the peaks of the prey population.

## **PRELIMINARY TRENDS**

We acknowledge there is very scarce data on conflicts and diseases simultaneously with good resolution and fidelity. Nevertheless we would like to point out some trends from whatever data sources do exist.

We add the caveat that there is very scarce data and the reliability and granularity with which this data was collected also needs to be critically examined.

In the future, it may be possible to capture data at higher granularity and build data driven mathematical models.

We show some trends using [gapminder.org](http://gapminder.org), open data and visualization platform. Figure 8 shows a visualization of deaths in battles (per 100 000 people) vs. deaths due to malaria. Shown are trends (no statistical significance or causation is implied) for three countries from 2002 to 2004. The visualization is freely available online.

For Angola, which had been suffering a war from 1975 to 2002, we observe that deaths in battles decreased over this timespan, whereas deaths due to malaria increased and then decreased.

The Democratic Republic of Congo (DRC) had been suffering from a war from 1998 to 2003. There is still an ongoing conflict with terrible casualties till date. For the DRC, we observe that battle deaths decrease over time and deaths due to malaria unfortunately show an increasing trend.

Unfortunately, Burundi has seen a steady increase in battle deaths with no visually appreciable trend in deaths due to malaria.

We would like to reiterate that we do not imply statistical significance or causality. The data sources and collection methods need to be critically examined. Our objective is only to highlight trends and make a case for a more concerted effort for data collection in conflict prone regions.

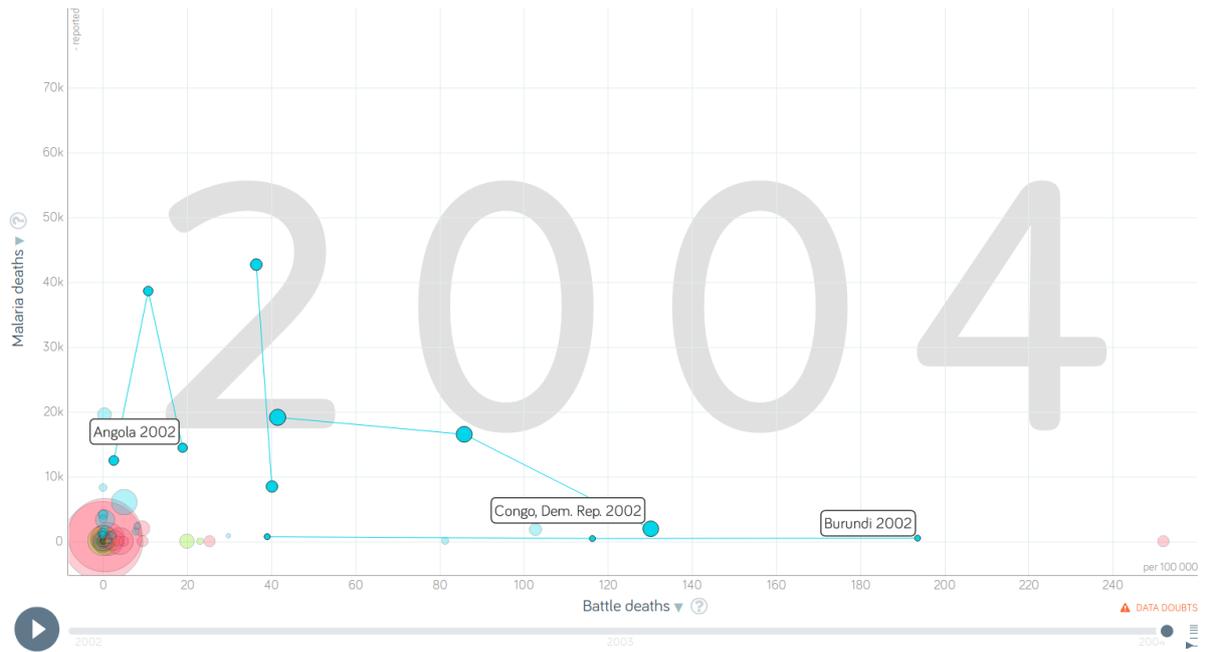
We also look at the number of refugees over time for three countries (Iran, Pakistan and Afghanistan) in a region that has seen conflicts for the last few decades, Figure 9.

We also look at health spending as a percentage of GDP for some countries, see Figure 10. We observe that for Burundi there was a small trend of increased spending on health whereas for Syria there has been a small decline. In the future, if there is reliable data, it may be possible to estimate the rate of recovery in SIR models (parameter  $n$ ) using these kinds of datasets.

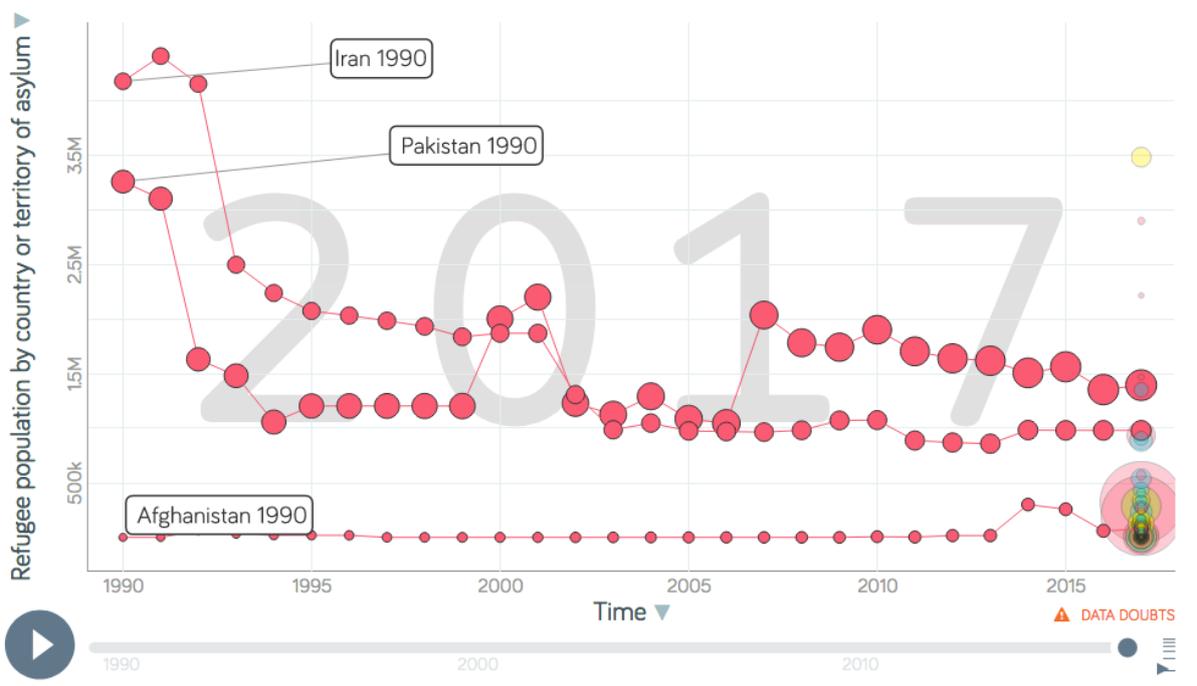
Overall, we find a disturbing trend of a global increase in the number of refugees over the last two decades [7]. This puts a large fraction of the world population at risk. This is also underscored by the current conflict and Ebola epidemic in the Democratic Republic of Congo as of 2019.

## **DISCUSSION**

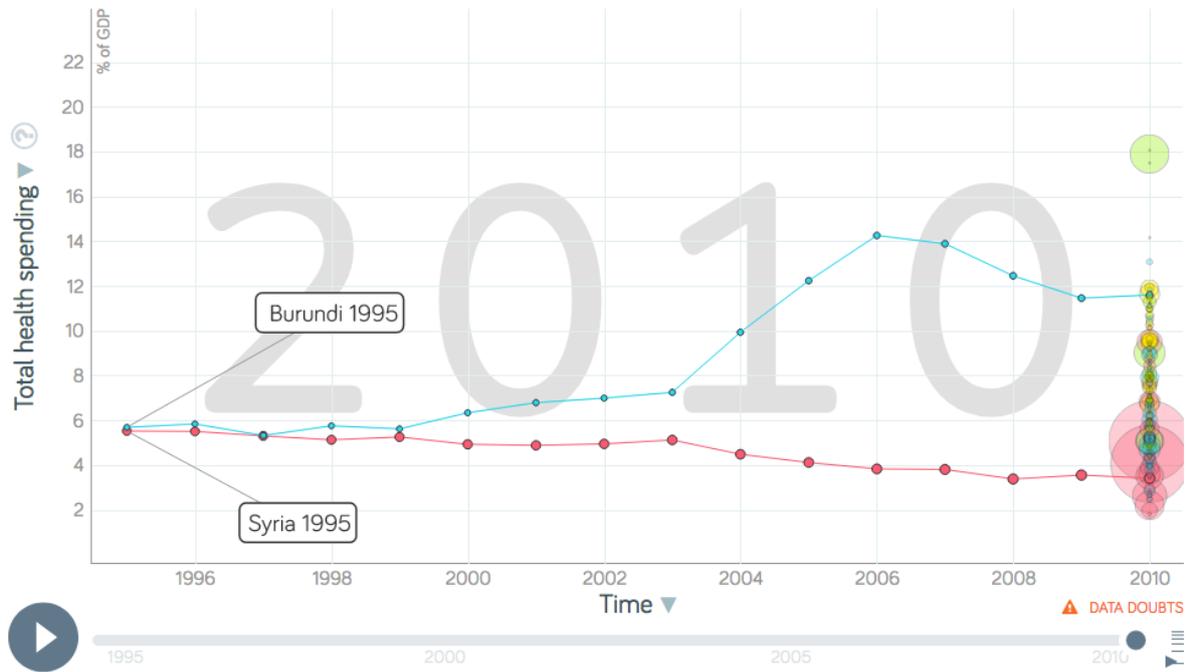
The effects of conflict on infectious diseases are multi-faceted and complex. There have been observations of both increase and decrease in disease outbreaks during conflicts. Epidemics have been observed to be both initiated and extinguished by conflicts [1]. However there is no unified mathematical model that explains all these counter-intuitive observations.



**Figure 8.** A visualization of deaths in battles vs. deaths due to malaria. The lines show a trend over time from 2002 to 2004 for three countries. The countries shown are Angola, Democratic Republic of Congo and Burundi. Based on free material from gapminder.org, CC-BY license. The visualization can be viewed online<sup>1</sup>.



**Figure 9.** A visualization of the number of refugees in Iran, Pakistan and Afghanistan over time. The lines show a trend over time from 1990 to 2017 for these three countries. Based on free material from gapminder.org, CC-BY license. The visualization can be viewed online<sup>2</sup>.



**Figure 10.** A visualization of the health spending as a percentage of GDP in Burundi and Syria over time. The lines show a trend over time from 1995 to 2010 for these three countries. Based on free material from gapminder.org, CC-BY license. The visualization can be viewed online<sup>3</sup>.

The recent appearance of emerging pathogens like Zika and Ebola virus in conflict-prone regions, highlights the need for a quantitative framework that integrates both diseases and conflicts.

Such models can be a first step towards policy, spreading public awareness and may also be a tool for public health professionals in conflict zones. Quantitative techniques like these may also help us predict possible emerging hotspots for emerging diseases [8].

In this work, we introduce a set of mathematical models to understand the role of conflicts in epidemics. Our mathematical framework has the potential to explain counterintuitive observations and the complex role of human conflicts in epidemics.

## THE ROLE OF NON-LINEAR MODELS IN UNDERSTANDING COMPLEX SYSTEMS

We suggest that non-linear mathematical models can help us understand why conflicts may both increase and decrease epidemics. We outline a few situations which explain the previously counter-intuitive observations. We develop coupled non-linear models of conflict, socio-economics and disease spread.

We show representative plots to demonstrate the role of dynamical systems in this field.

We note that the models are not specific to any disease nor do we estimate model parameters specific to any pathogen. Our objective is only to demonstrate that such a situation is indeed feasible. It should be possible to fit similar mathematical models to data, once such data becomes available. We note that the type of disease also matters. For example, a vector-borne disease will have different characteristics compared to sexually transmitted diseases. Hence diseases may have different effects on conflicts based on their type and mode of transmission.

Conflicts also cause a higher incidence of stress and trauma related diseases like diabetes and strokes [9].

Conflicts can also help introduce new pathogens. Invading armies can introduce new diseases to a population that has no immunity (the English and the American armies introduced smallpox to Native Americans) or the invading army itself may be exposed to a novel pathogen (Napoleon's army suffered from typhus during the Russian invasion) [10]. We speculate that diseases may, in certain cases, even pause conflicts.

## **POLICY IMPLICATIONS**

At the end of conflicts, epidemics could go away or reappear due to migration of aid workers, displaced populace, etc. Timely humanitarian intervention is key to reducing the spread of diseases.

The policy implications are that public health officials will need to work closely with peacekeeping missions and humanitarian aid workers to manage crises, both during and after conflicts.

Migration has a significant effect on infectious diseases during and after conflicts. This suggests that steps taken to manage refugee crises during and after conflicts are critical in preventing outbreaks of infectious diseases.

Our models demonstrate the vicious cycle of poverty, disease and conflicts, especially in some developing nations. Diseases can cause more poverty due to the increased public health burden. Ultimately this may also lead to conditions that encourage conflicts for resources.

This suggests that aid and peacekeeping organizations should take an integrated approach that combines:

- 1) public health measures,
- 2) efforts to aid socio-economic development,
- 3) peacekeeping in the region.

We also suggest that managing public health crises and reducing poverty can have significant knock-on effects including, we hope optimistically, reduction of conflicts. It is intriguing to speculate that perhaps an integrated approach where public health intervention is coupled with nation-building efforts, for example to build technological infrastructure and international scientific collaboration networks, may help these countries recover in the long term [11].

We do however acknowledge the difficulties that humanitarian organizations will face in reaching communities during times of conflict.

## **FUTURE WORK**

There are certain aspects of this complex system that we have not incorporated which may form the subject of future investigations. We outline some of those factors here. Human trafficking during and after conflicts is an unfortunately common occurrence in conflict zones. The trauma it leaves behind in victims alone is unfathomable. Humanitarian aid or peacekeeping organizations also sometimes unfortunately exploit people in conflict zones, as has happened in the Yugoslavia in the 1990s and more recently in Haiti. These incidents inflict further trauma on the victims. They also erode trust in these organizations and further delay and complicate recovery efforts after conflicts.

Another area of future investigation will be the humanitarian and ethical aspects and other benefits that come from welcoming refugees and displaced people. Refugees can bring in a lot of diversity into another country and enrich it in many ways [8]. We can investigate how foreign aid and influx of refugees can help these countries recover after conflicts.

## CONCLUSION

This work is a step towards a quantitative model of disease spread in conflicts. Our model explains apparently inconsistent observations on disease spread during conflicts. A multitude of possibilities are explained in a quantitative framework. Our work also highlights the importance of simple mathematical models and the perils of applying linear thinking to non-linear complex systems. Non-linear models produce counter-intuitive results; disease spread is a non-linear phenomenon which produces counter-intuitive results. Such mathematical models have been used in the past to model diverse complex systems ranging from socio-economic to biological systems [2]. We note that similar mathematical models have also been used to explain crime and violence in human societies [8].

Our work raises the hope for a predictive model that may be of use to first responders and public health officials in conflict hotspots. Mathematical models of joint epidemic and conflict risk would be of considerable interest to future humanitarian and peacekeeping missions.

## ACKNOWLEDGEMENTS

This work is dedicated to Dadu. This is also dedicated to the millions of people around the world who are affected by conflicts, diseases, forced migration and human trafficking.

## REMARKS

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<sup>2</sup>[https://www.gapminder.org/tools/#\\$state\\$time\\$value=2017&delay:1179;&marker\\$select@country=afg&trailStartTime=1990;&\\$country=pak&trailStartTime=1990&labelOffset@:0.382&:0.051;;&\\$country=irn&trailStartTime=1990&labelOffset@:0.28&:0.027;;;&axis\\_x\\$which=time&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&scaleType=time&spaceRef:null;&axis\\_y\\$data=data\\_wdi&which=sm\\_pop\\_refg&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&spaceRef:null;;;&chart-type=bubbles](https://www.gapminder.org/tools/#$state$time$value=2017&delay:1179;&marker$select@country=afg&trailStartTime=1990;&$country=pak&trailStartTime=1990&labelOffset@:0.382&:0.051;;&$country=irn&trailStartTime=1990&labelOffset@:0.28&:0.027;;;&axis_x$which=time&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&scaleType=time&spaceRef:null;&axis_y$data=data_wdi&which=sm_pop_refg&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&spaceRef:null;;;&chart-type=bubbles).

<sup>3</sup>[https://www.gapminder.org/tools/#\\$state\\$time\\$value=2010&delay:1179;&marker\\$select@country=bdi&trailStartTime=1995&labelOffset@:0.249&:-0.192;;&\\$country=syr&trailStartTime=1995&labelOffset@:0.206&:0.18;;;&axis\\_x\\$which=time&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&scaleType=time&spaceRef:null;&axis\\_y\\$which=total\\_health\\_spending\\_percent\\_of\\_gdp&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&spaceRef:null;;;&chart-type=bubbles](https://www.gapminder.org/tools/#$state$time$value=2010&delay:1179;&marker$select@country=bdi&trailStartTime=1995&labelOffset@:0.249&:-0.192;;&$country=syr&trailStartTime=1995&labelOffset@:0.206&:0.18;;;&axis_x$which=time&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&scaleType=time&spaceRef:null;&axis_y$which=total_health_spending_percent_of_gdp&domainMin:null&domainMax:null&zoomedMin:null&zoomedMax:null&spaceRef:null;;;&chart-type=bubbles).

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# ECG SIMULATION AND INTEGRATION OF KALMAN FILTER IN CARDIO PEDIATRIC CASES

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## ABSTRACT

This article will show an overview of the model and simulations of general cardio pediatrics cases. To avoid simulated interference, Kalman and lowpass filter blocks are placed. In pediatric cases normal ECG (Electrocardiogram) curve is a bit different in relation to the middle-age persons. In cardio pediatric is represented especially the ECG curve with higher beats/min. Depending on the age of the child's heart rate is variable. Therefore, identifying irregularities of the heart rate in children should be implemented a particular type of filter to eliminate rough measurement error on measurement signals. The model is obtained computationally shown in the examples of simulation in LabView and Java application programming interfaces. The model realization of the ECG signal is based on a few methods. Therefore, it selected only one method to display a simulated ECG signal. Installation of additional software filters allows us for realistic expectations after hardware integration. The real practical case is provided by a developed system with compiled firmware in the microcontroller. Firmware defines the behavior of the ECG signal after the integration of Kalman and the lowpass filter. Some cardio pediatric cases are processed with the method which can be applied Kalman or lowpass filter.

## KEY WORDS

ECG model, ECG Simulation, Kalman filter, low-pass filter, smart city

## CLASSIFICATION

JEL: Q53, R41

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## INTRODUCTION

The realization of the ECG signal simulator for cardio pediatric cases requires the development of the model. With additional model possibilities like parameter adjustment, a waveform of the ECG curve is defined. The model parameters depend on a lot of specifics that can occur in children's cases e.g. one of the specificities of the right ventricular hypertrophy is when V1 is different and changes with ages. How the heart grows, operational frequency is reduced and minute volume is held. Specificity can be seen in the T wave, which is the subject of electrolyte status activity of the autonomic nervous system. Transition to the ST segment does not contain significant changes or specifics unless a child has ischemia. That case is then defined by the pressure or volume load of the right ventricle in the right precordial leads. Using V4, V5 and V6 (left leads) can be displayed when the left ventricle is loaded, then is a case of aortic stenosis difficult. Very important parameters for simulation of the ECG curves in cardio pediatric cases are V1, V2, V3, and V4 lead. Negative or inverted signals are characteristic of cardio pediatric cases and children's cases for up to 12 years. This is the case for V1 – V4 leads. Later, after 12 years of the child may remain inverted signal in V1 and V2 leads. Between 17 – 18 years usually lead V1 becomes positive, non-inverted. Some people have a whole life negative/inverted V1. Pleasantly we call them in discussions forever young.

During measurements of heart rate, results show different frequencies at various ages and lifetime of child Table 1. The fluctuation of heart rate is in the age range from 3 30 days and 1 – 3 months. There occur of the highest frequency because the fiber of muscle on the heart is formed. For the knowledge of the heartbeat and creating/simulate curves, it is necessary to recall the appearance of the heart (ventricle and atrium) and the ideal/basic global curve of ECG waveform signal Figure 1 a) and b).

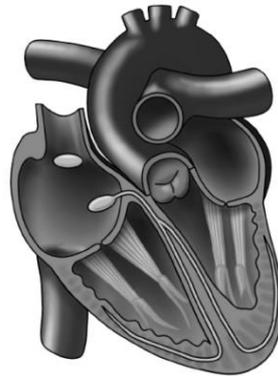
**Table 1.** Heart rate by children ages.

Heart rate (bpm)		
Age	Mean	Range
< 1 day	119	94-145
1-7 days	133	100-175
3-30 days	163	115-190
1-3 months	154	124-190
3-6 months	140	111-179
6-12 months	140	112-177
1-3 years	126	98-163
3-5 years	98	65-132
5-8 years	96	70-115
8-12 years	79	55-107
12-16 years	75	55-102

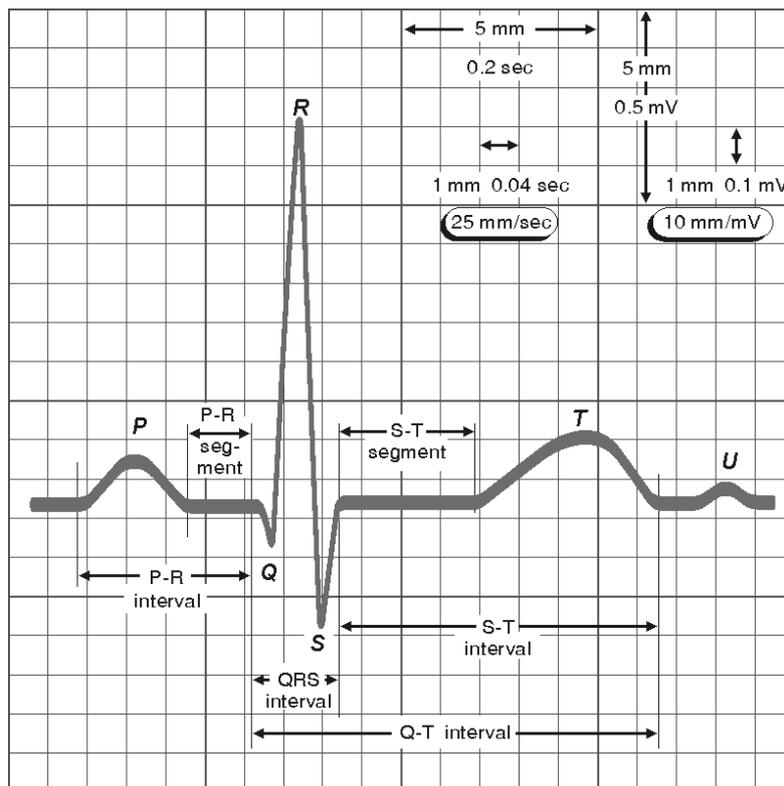
The model of the ECG signal is manifested thought a 3D model of the heart [1]. The Mash network of lines on the model defines density and tissue form [1]. To form a 3D image/model of the heart is necessary to make a mathematical model [1-3]. Substituting the parameters in a mathematical model, it is created dynamically model and emulation of the heartbeat.

Important criteria used to observe the specificity of right ventricular hypertrophy when is the R more than 20 mm in V1 through all the years, R/S ratio more than 6.5mm and upright T wave in V4 after 72 h of life. Also, the presence of a Q wave in V1 is part of the criteria. Left ventricular hypertrophy is defined when the S is more than 20 mm in V1, R more than 20 mm in V6, and Q wave more than 4 mm in V5 and V6. Also, T wave inversion in V5 and V6 characterize these criteria [4-7].

In cardio pediatric cases is included several forms of normal rhythms of heartbeats such as normal sinus rhythm, normal sinus rhythm at arrhythmia and sinus tachycardia. Characteristic description of normal sinus rhythm describes regular regularity at 60-100 bpm (beats per minute). Also, the QRS complex is less than 120 ms. The only difference in sinus arrhythmia is irregular regularity. The characteristic of sinus tachycardia is that regularity is regular but the heart rate is greater than 100 bpm. Except for those phenomena, fast and slow rhythm is also represented [8].



a)



b)

**Figure 1.** a) Appearance of the heart, b) Ideal/basic global curve of ECG waveform signal.

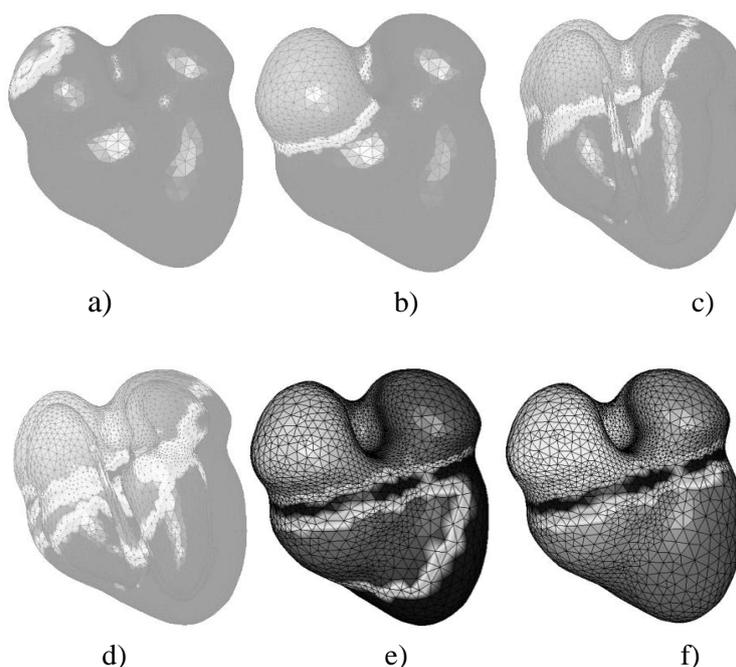
## 3D MODEL OF HEART AND ECG SIGNAL SIMULATION

### 3D MODEL OF HEART

Mathematical modeling of ECG is known as the forward problem of electrocardiography. There are three basic types of the model; a model for electrical activity of heart, model

calculating torso and heart-torso coupling model of conditions. With space and time discretization numerical results are obtained [2].

The dynamical model creates and generates a trajectory in a three-dimensional space. Applying integral equations to mathematical models, 3D models are obtained, Figure 2. Through six frames is shown characteristic appearances like membrane potential, TNNP (Tusscher-Noble-Noble-Panfilov) ionic model and repolarization or relaxation of the ventricles in T wave, Figure 2. According to the fractal behavior method for the dynamical model is possible to be dimensioned. Similar methods of identification of processes, recursively repeated with small phase shifts, describes cardiac nature. Precisely, these phase shifts are defined by the nature of acceleration and deceleration of the heartbeat [9].



**Figure 2.** Heart 3D model (dynamics of behavior).

## ECG SIMULATION

To accurately simulate the ECG curve in cardio pediatric cases it is necessary to create a simulator that has the option of entering parameters. Besides the basic parameters that characterize the ECG curve, sometimes is added to simulation: temperature, main pressure, diastolic pressure, systolic pressure and oxygen saturation. The important parameter used in LabView ECG simulator is “spacer width” which may lead to the characteristic movements that are essential for cardio pediatrics. Exactly this parameter is included as a slider in a graphical interface that the ECG curve can be faithfully simulated. Throughout the paper, we use two simulators. Primary ECG simulator over which is made modifications with filter block using LabView interface. A secondary ECG simulator is implemented in Java and interference has not eliminated in that case.

The basic interface for configuring the simulator defines the appearance of the ECG curve Figure 3. A block diagram of the global system design of the ECG signal is shown in Figure 4. Design of white noise and other parameters in blocks that simulate real interference has been achieved in the waveform of ECG signal in Figure 5. To see the difference in the simulated signals, the scenario is divided into three segments with different heartbeats. Thus are defined 68 bpm, 115 bpm and 155 bpm.

Basic simulated ECG signal with 68 bpm with a graphic interface for setting the parameters is shown in Figure 6. Figure 7 a) and b) represents a curve of ECG signals with 115 and 155 bpm. The integration of block diagram to generate white noise and amplitude amplification for virtual emulation of artifacts produced an effect on the curve that improves Kalman or lowpass filter, Figure 8 a) and b).

For reduction of the white noise has been used lowpass filter. To remove the component of motion artifacts during the measurement is used Kalman filter. In the third subtitle is defined lowpass and integration of Kalman filter. After signal omission, an ideal model of signals is obtained and faithful to the original signals.

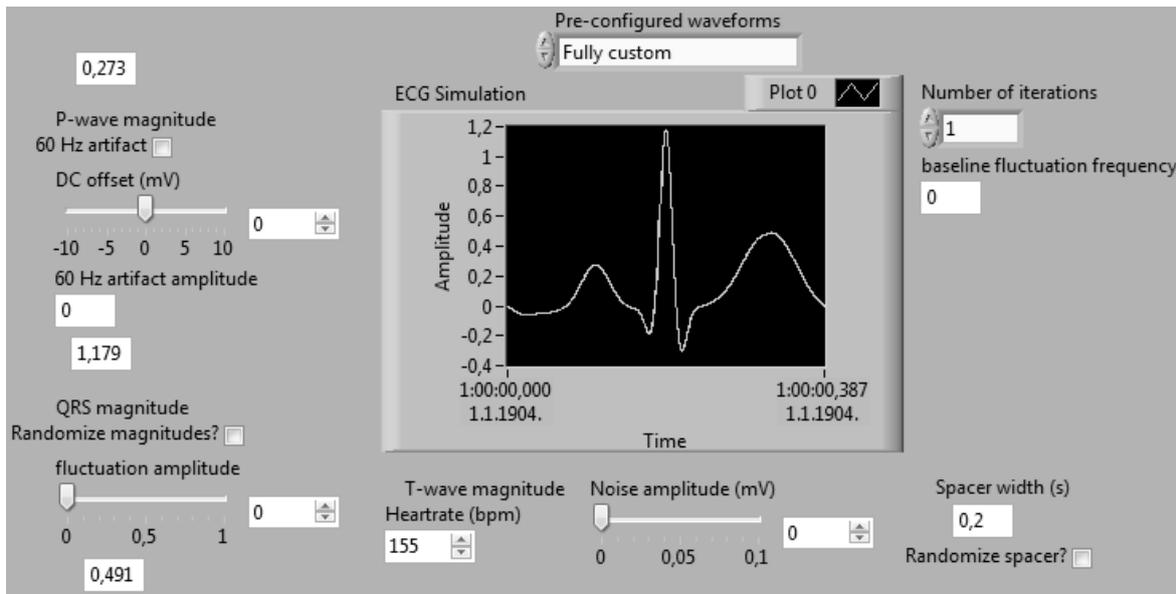


Figure 3. Basic interface for ECG curve design.

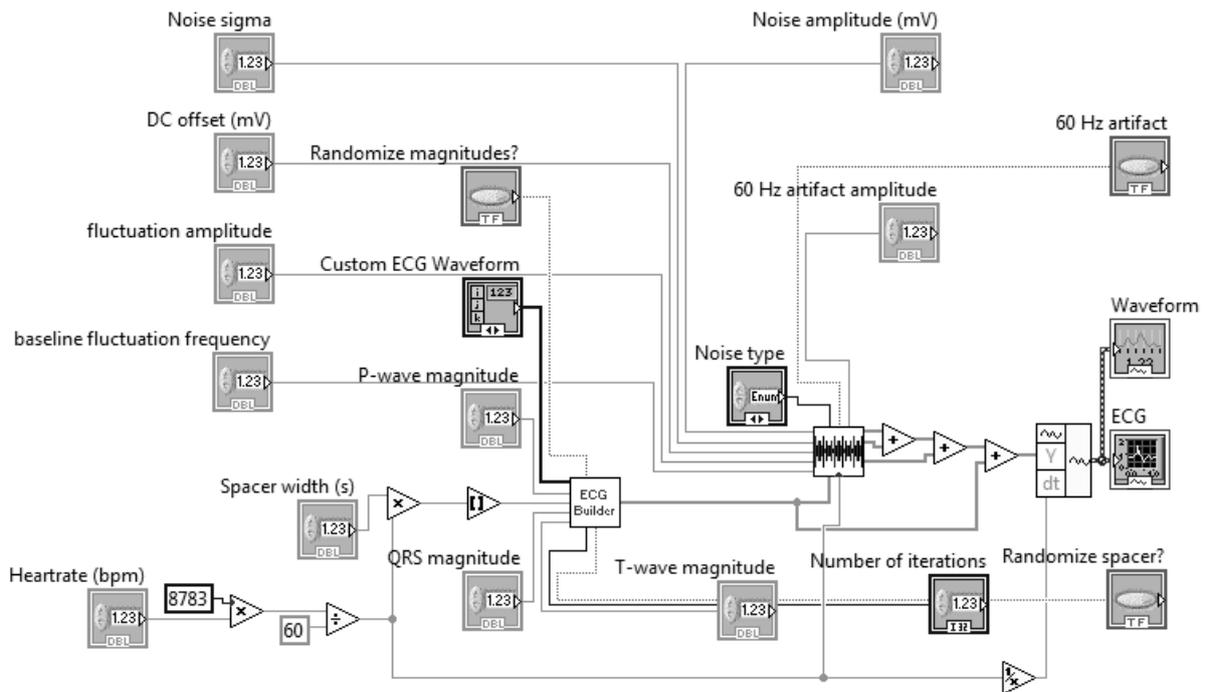


Figure 4. Block diagram of global simulation design of ECG signal.

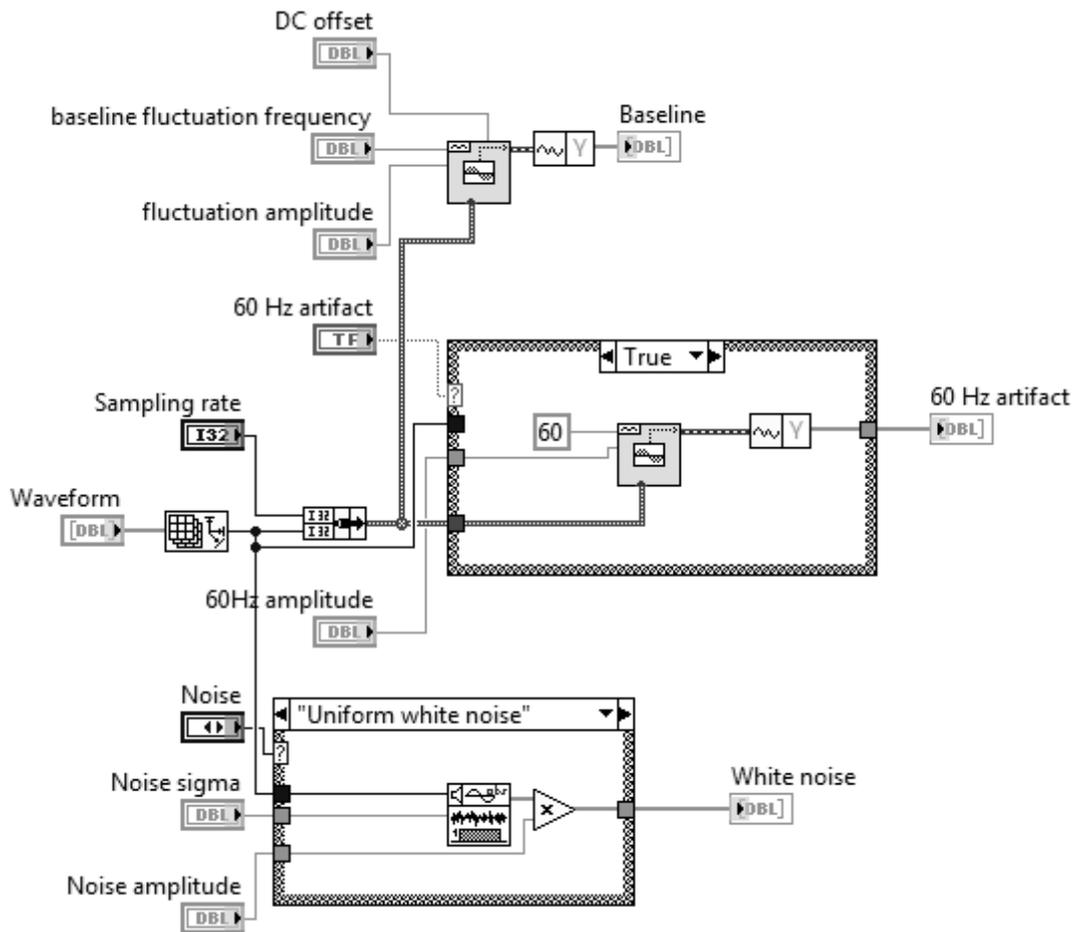


Figure 5. Block diagram of noise.

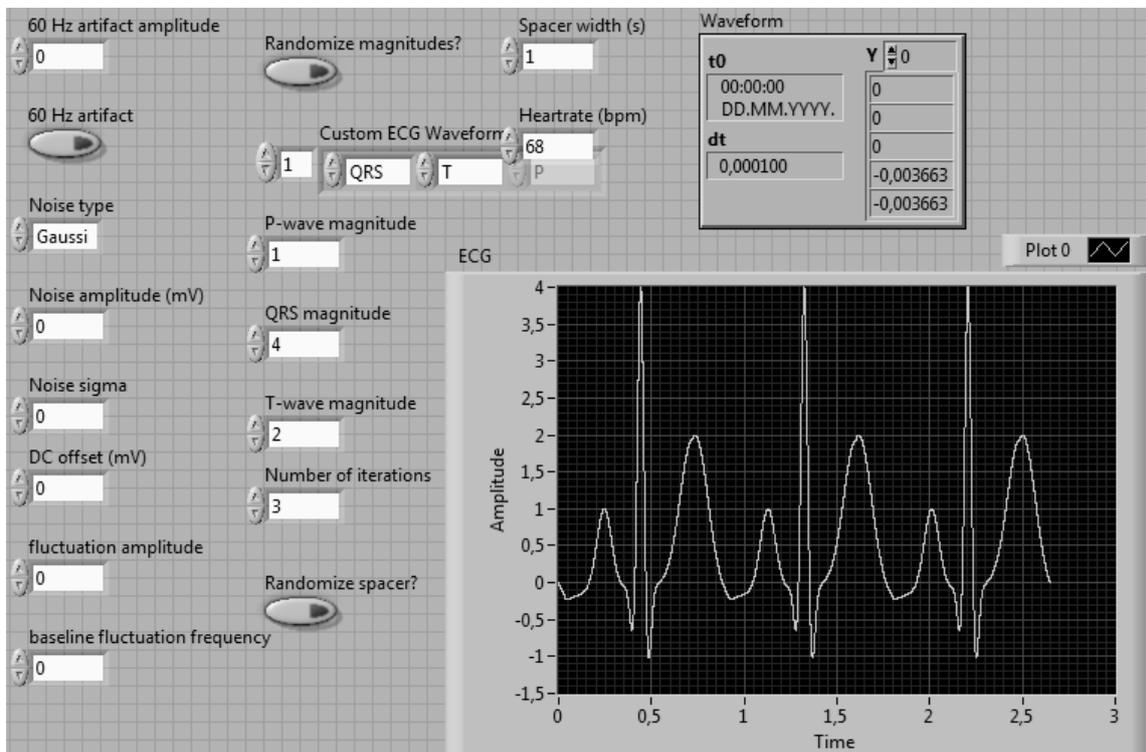
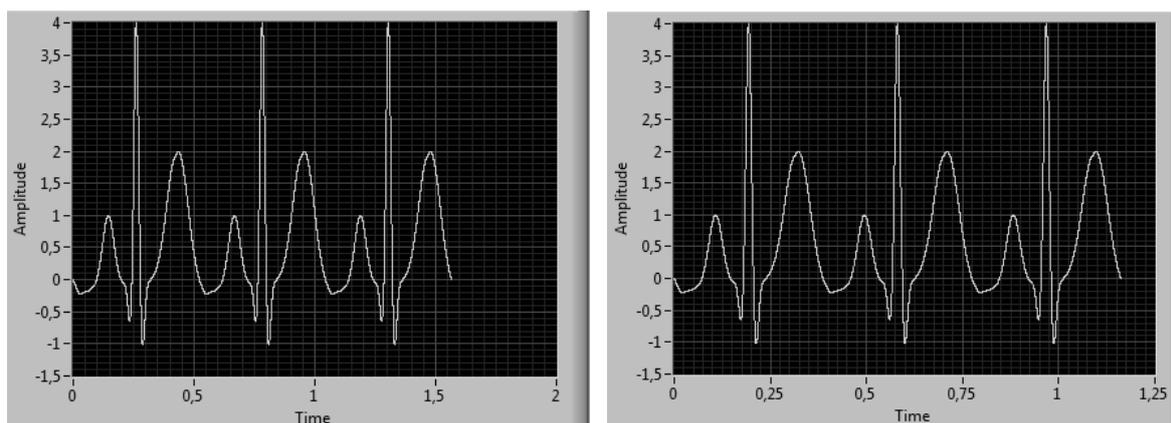
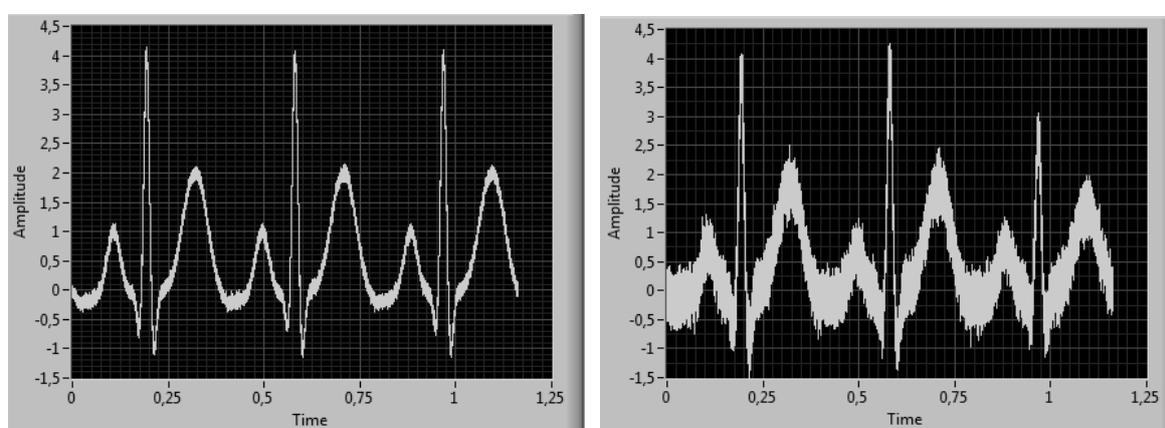


Figure 6. Secondary graphical interface for parameter adjustment (68 bpm).



a)

b)

**Figure 7.** ECG signal a) at 115 bpm, and b) at 155 bpm.

a)

b)

**Figure 8.** ECG signal a) at 155 bpm with white noise, and b) at 155 bpm with 2 mV amplitude noise.

Smaller quantization in hardware is monitored and filtered by setting a limit of real filter, while developed simulation at the same clock data is faster processed. Comparing to the existing simulators, Figure 9, which has integrated parameters such as body temperature, surface skin temperature, pressure, etc. It is possible to display a more faithful signal [10]. Very important parameters for adjustment in the existing simulator are heart rate, oxygen saturation and PPG (Photoplethysmograph) which we can bring from additional hardware mobile measurement devices called oximeter [11-13]. With SPO<sub>2</sub> (Saturation of peripheral Oxygen) and mounting real oximeter, with additional measurements is easier to determine the condition of the patient. Another simulator of ECG signals was realized through Java compiled and uploaded an online interface where we can also change parameters, Figure 10. Changing values of parameters for different waveforms with simultaneous creation of logging files is achieved [14-15]. Then such a file can be analyzed separately and we can use null-points for simulated curves. Elements inserted for adding artifacts impairments include the low voltages that modulate to the ideal ECG curve.

Figures 11 and 12 represent the Java online simulator of ECG signals with an amplitude noise of 0,2 mV and 0,5 mV. Filtering, in this case, is not realized in Java programming code. Creating additional program code form in shape of “for” loop, counting to 10 and with fragmentation system can eliminate undesirable interference and characterizes the case behavior of the Kalman filter effect. White noise is possible to integrate with the function “randomize” where the number of offsets limit can be constrained by software.

Filtering white noise in the same simulator software can be provided graphically in LabView or with standard Java code. Kalman has two types of integration of filter; matrix and with “for” loop where is loop options mostly used for integration into embedded devices.

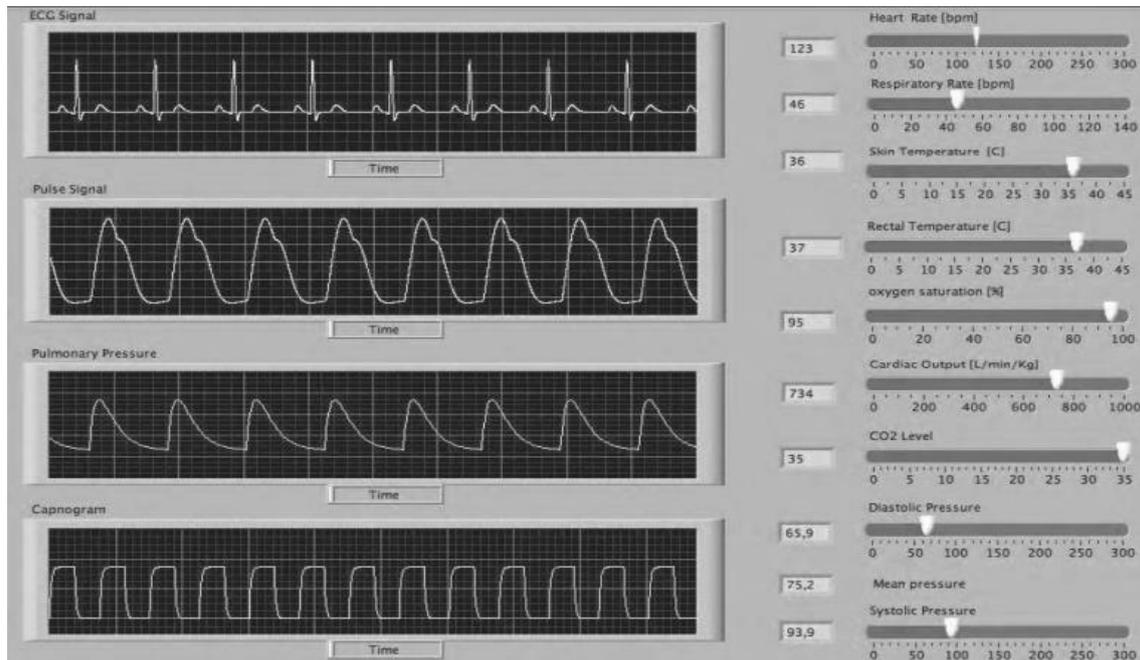


Figure 9. Existing ECG simulator without filtering and modeling noise.

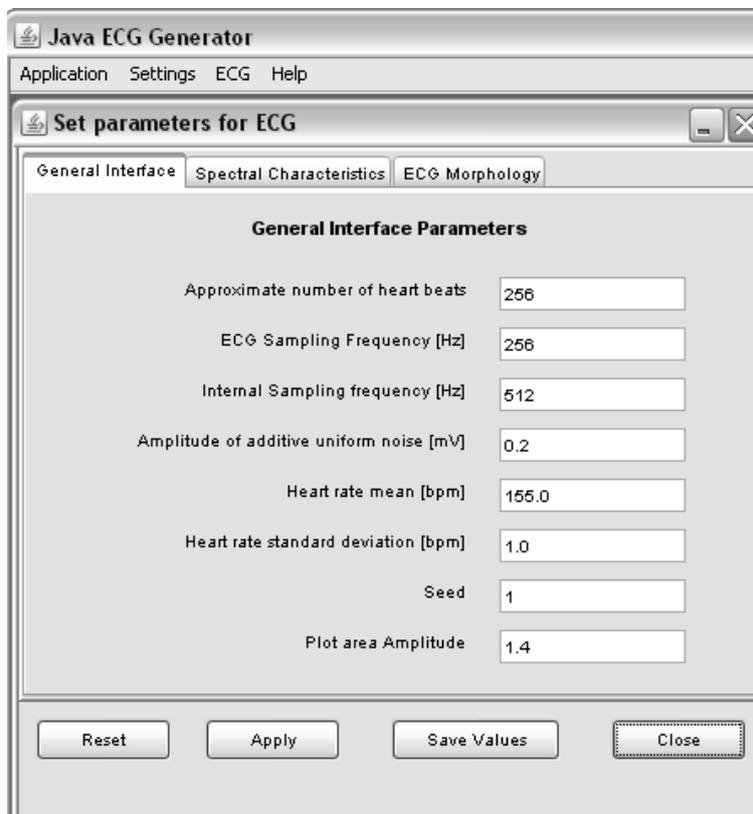


Figure 10. Java ECG simulator/generator [14, 15].

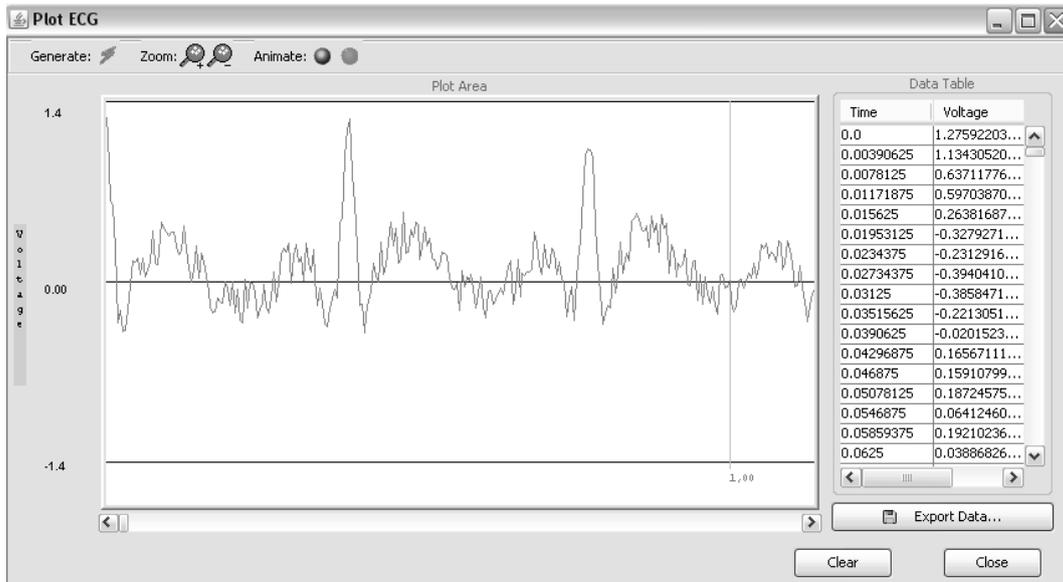


Figure 11. Java ECG simulator with amplitude noise 0,2 mV.

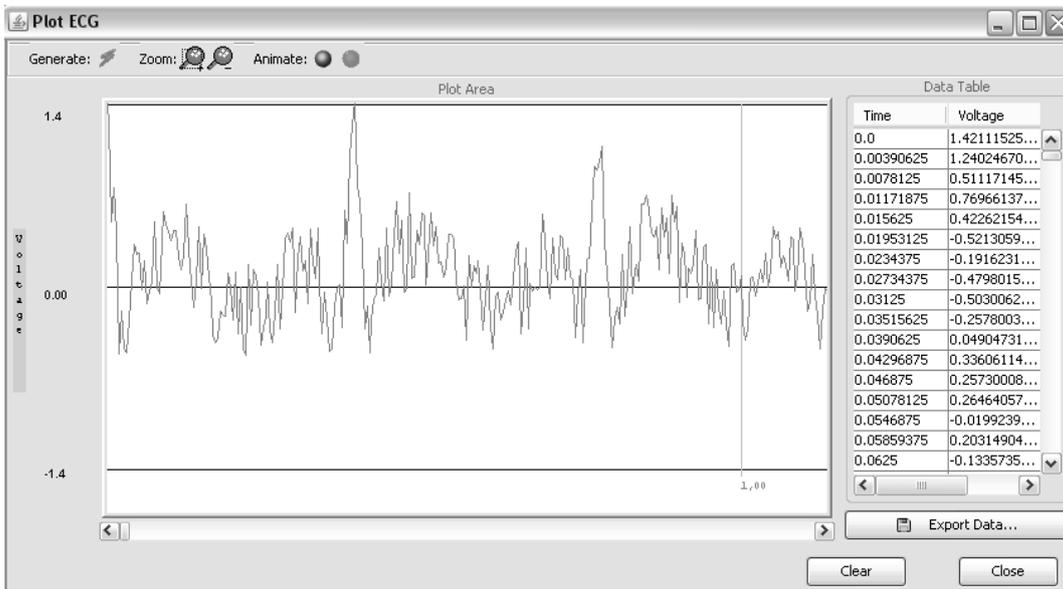
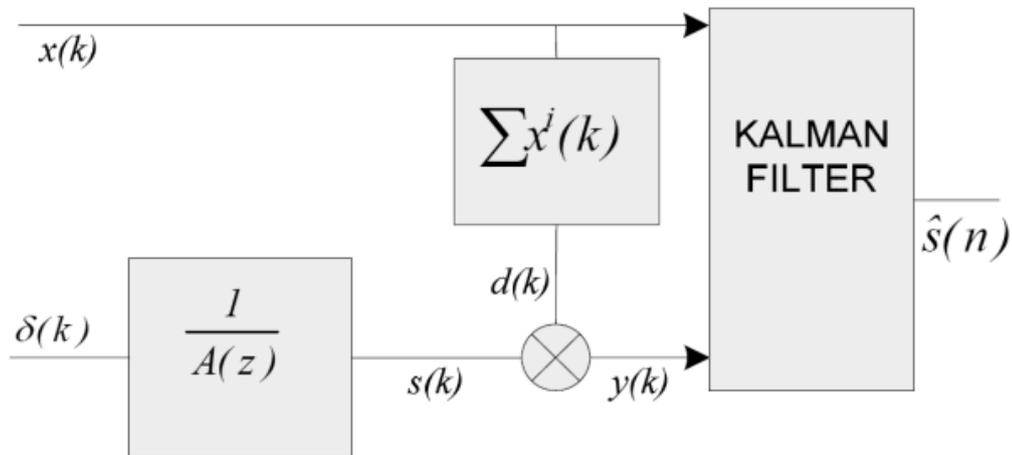


Figure 12. Java ECG simulator with amplitude noise 0,5 mV.

## INTEGRATION OF LOWPASS AND KALMAN FILTER IN SIMULATOR

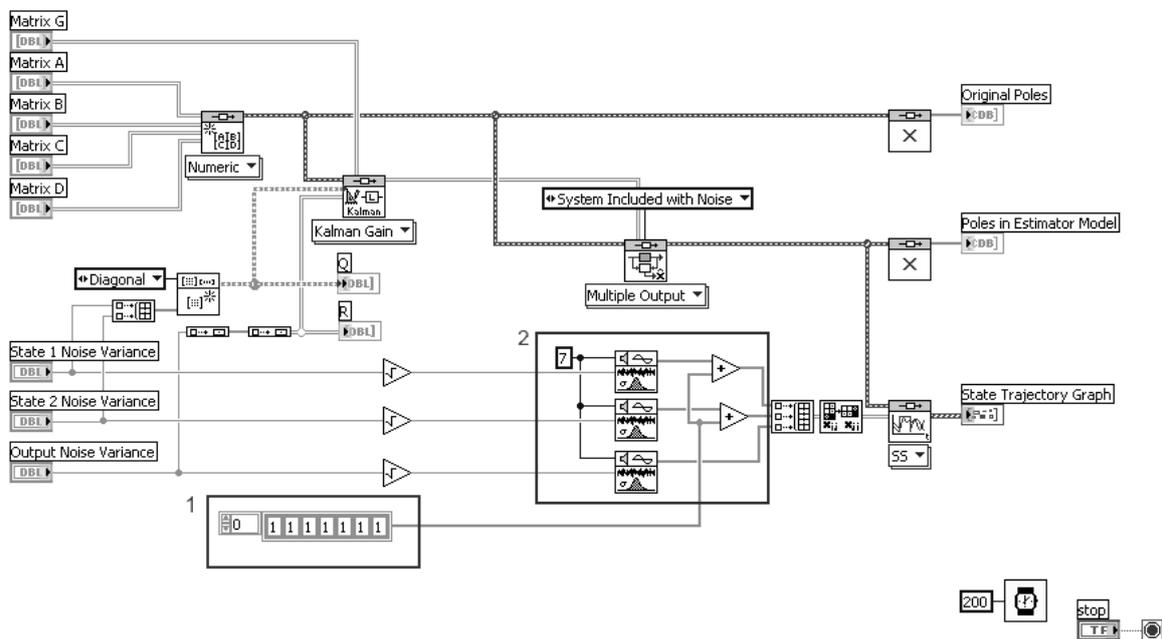
Kalman filter integration in LabView simulator requests known process frequency. Kalman filter is used for parameterization of various processes and is applied in this simulator. Many processes use Kalman filter such as calculation of the angle of multirotor/quadcopter [16-18]. During logging and processing, all three axes of accelerometer, gyroscope, and magnetometer must be filtered signals. Also, e.g., a self-balancing vehicle with an accelerometer and gyroscope have integrated Kalman filter to reduce the effect of drift [19, 20]. Scenarios where variables are not linear its used Extended Kalman filter. Signal analysis of previous applications bringing us to the conclusion that such application of filter brings very good results in the processing of ECG signals. Besides the simulator, the idea is to integrate the filter into the firmware of the embedded device.

To analyze and process the signal, it is necessary to make discretization. Using inverse delta function  $d(k)$  with characteristic adjusted amplification, adder processes output value for Kalman filter, Figure 13.



**Figure 13.** Model of signal value preparation for Kalman filter processes.

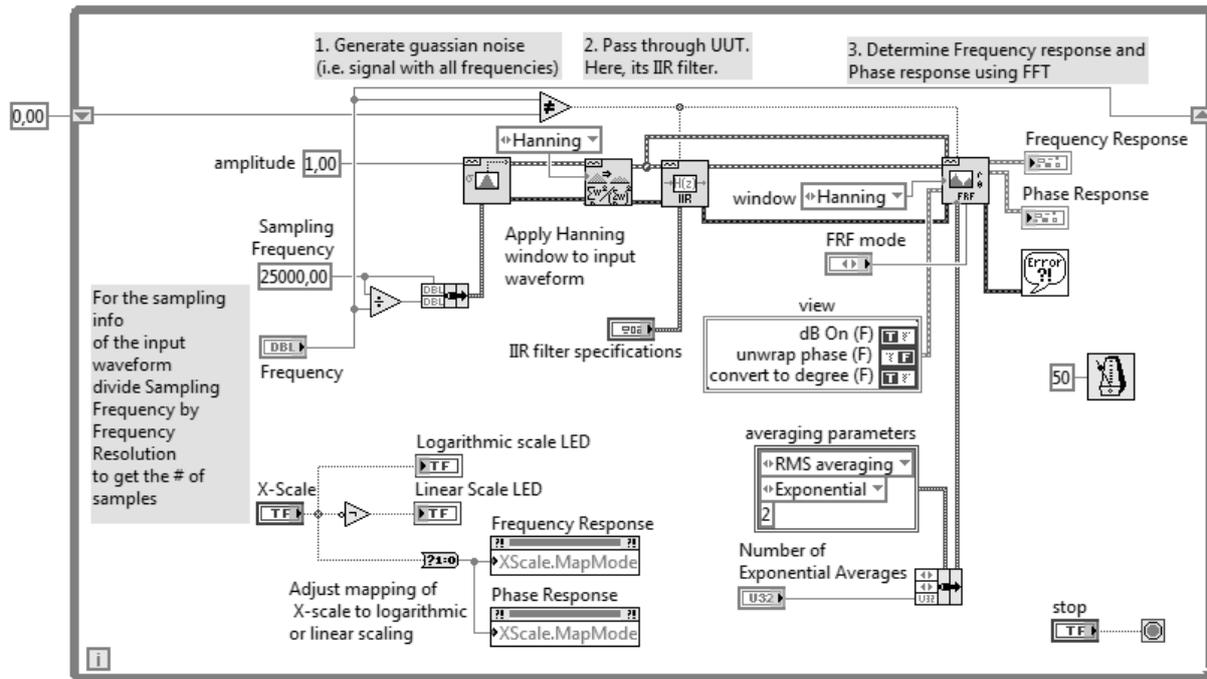
Presented filter block can be realized using a matrix of discrete mathematical relations or by using loops inside the software. This software can be integrated into a computer simulation and incorporated into the firmware of an embedded microcontroller device. Application of ECG simulator in LabView was used for filtering systems on Kalman/matrix principle, Figure 14. Possibilities for filtering can be processed with “for” loop counting to 10. “Shredding” of the signal in this way is less obtained, accurate and filtered response. How it is difficult to incorporate matrix form in an embedded device, preparation for future work is installing a filter in measuring system of ECG via loop principle. After taking ten samples of measurements at a much higher frequency, the variable is bit shifted and divided by ten.



**Figure 14.** Matrix principle of integrated Kalman filter in ECG simulator.

Earlier mentioned matrix principle uses some additional operation over the matrix-like transposing. Integration to the planned embedded device is not suitable for this operation because it is necessary to ensure bigger processor power on higher frequencies.

Lowpass filter integration can be efficiently designed in software and hardware. Function integration in software simulation separates characteristic frequencies while in hardware it is passive electronic used with resistor and capacitor integrated on each channel. The lowpass



**Figure 15.** Design of Butterworth lowpass and bandpass filter

filter is usually used for isolating harmonic from the power network. There appears a frequency of 50 Hz or 60 Hz with the prescribed tolerance in Hz, and their presence, because electromagnetic compatibility must be isolated as rough measurement error. Figure 15 represents the design of two integrated filters based on the Butterworth principle. Integration of Butterworth lowpass filter is for the elimination of low frequencies like mentioned, 50 Hz and 60 Hz.

Figure 16 represents a Butterworth lowpass filter, while Butterworth bandpass filter is finally integrated because our muscles and natural movements represent high frequencies. For elimination of these frequencies is necessary to integrate high pass filter. With this solution with bandpass filter integration, Figure 17 was achieved and prepared for the installation of a dynamic Kalman filter. Prescribed frequencies that are specified for measuring ECG signals are 100-150 Hz. With an obligatory sampling of the signal during measurement on mobile embedded devices its between 1-2 kHz minimum. Industrial devices, designed for hospitals and clinics, must have higher sampling frequency.

ECG signals sometimes in real conditions has a dynamic component of interference or noise. Superelevation or some doctors say overshoot, after filtration by ordinary filters in characteristic points, can lead to making the wrong diagnosis, especially in the ST segment. To avoid this situation, Kalman filter with very low latency/delay of filtering, (below 1ms), in this application provides real-time measurement. Referring to the dynamic ECG model [21, 22], it is possible to use EKF (Extended Kalman Filter). The basic feature of the EKF is nonlinearity compared to standard Kalman filter as is mentioned before. To linearize nonlinear dynamic model must be linearized model through state-equations [2, 3, 7, 22]. Estimation of signal trough EKF requires parameterization [22-23]. In practice, when after measuring the ECG signal is integrated, EKF proved to be further improved in readings [24-26]. Through practice it turned out that older cardiologists and cardio pediatricians have been well adapted to the nuisance so-called; offset that can be understood without the need for additional integration into small portable devices. In professional desktop devices, which is used to measure ECG signals, such EKF is integrated for additional analyzes.

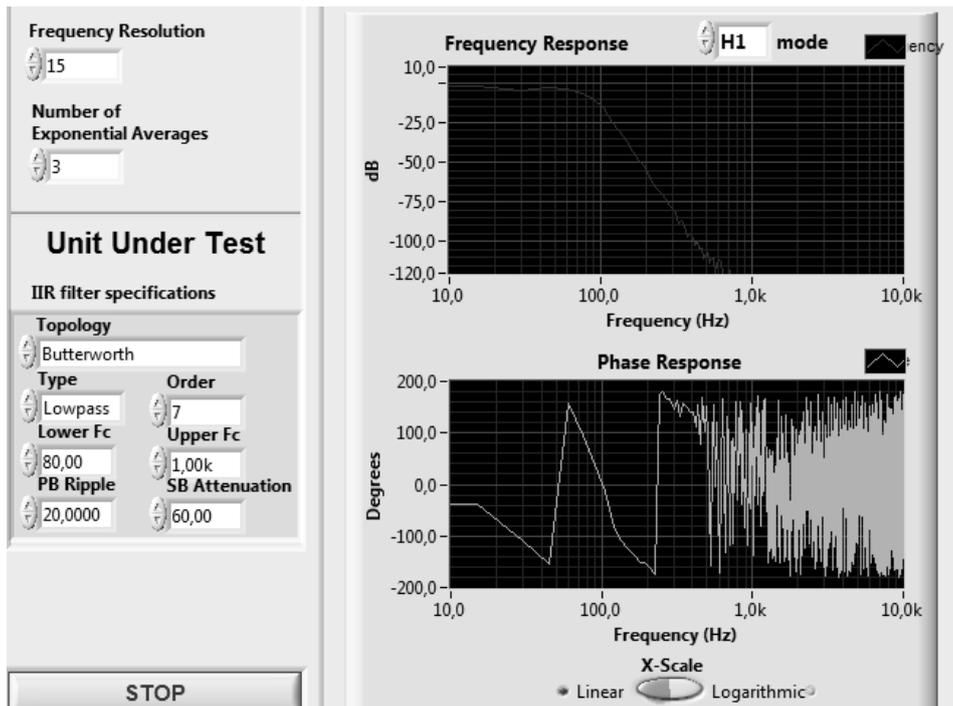


Figure 16. Butterworth lowpass filter.

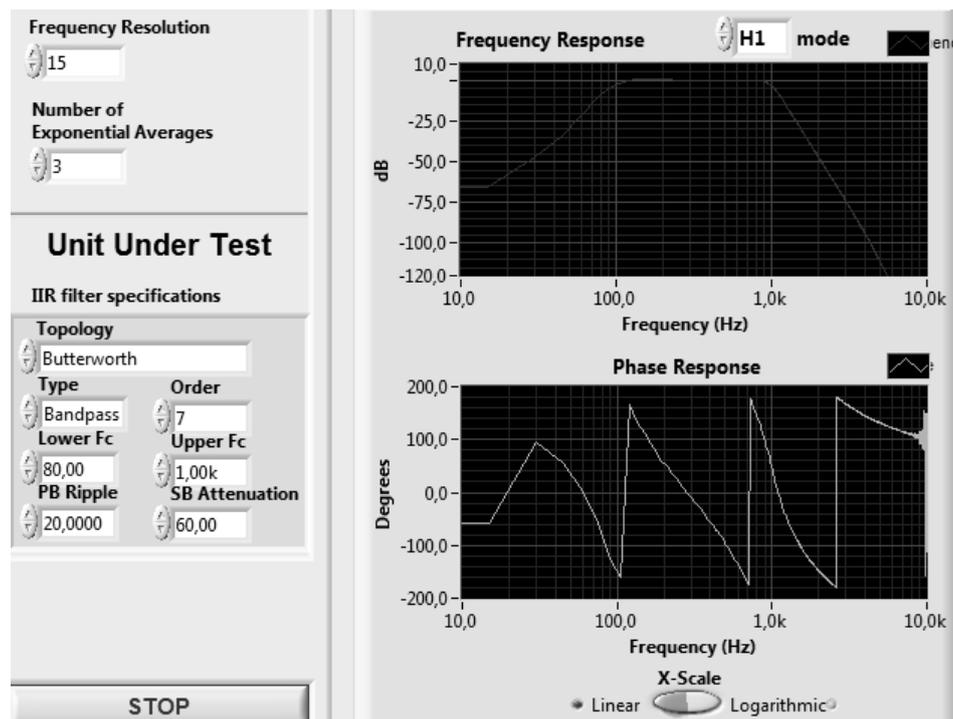


Figure 17. Butterworth bandpass filter.

## CONCLUSION

During the development of ECG signal simulation, we took into consideration existing mathematical models of the heart. 3D model of the heart is shown through isometrics dynamic events, Fig. 2. During the elimination of interference, first was used Butterworth bandpass filter. The second filter in real-time analysis, for assumed embedded device integration is used on the Kalman filter “loop” principle. Kalman filter is shown through the matrix form with matrix transposition while it is taken into consideration the standard

Kalman “loop” method for easier integration in embedded devices. Upper classes, such as the ability to use FPGA (VHDL programming), allow us for the integration of matrix Kalman filter, but in such cases, it is used Extended Kalman filtering (EKF). Simulation results show average R-RF time between 7-8 ms at 60 heartbeat rate, while the R-R segment is 735 ms. The integration of all filters is considered for implementation in an embedded microcontroller device for wireless monitoring. The same principle is used in Holter devices but without Kalman “loop” filter integration. Thus, achieving off-line analysis with recording 24-hour log on SD card. ECG simulations and filter integration provide us with techniques to integrate and work in real-time on an embedded wireless device. By Kalman filter is achieved the elimination of superelevation/overshoot and less time is necessary for filtering (below 1ms). Results represent a very small delay compared to existing solutions. This method of filter implementation in cardio pediatric cases exactly is suitable for a larger number of beats because the method precisely enhances analysis and diagnosis creation of the patient.

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# MOBILE ECG AND SPO2 CHEST PAIN SUBJECTIVE INDICATORS OF PATIENT WITH GPS LOCATION IN SMART CITIES

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## ABSTRACT

Subjective indicators of chest pain in this article describe a system based on devices for measuring ECG (Electrocardiogram) and SPO2 (Saturation of peripheral Oxygen) signals with PPG (Photoplethysmograph). The development system used for ECG detection signals is created in the SMT technology technique. Preparing for ECG (Electrocardiogram) signal analysis is realized on the coordinator side of the WSN (Wireless Sensor Network) node and LabView application interface. Existing model RPC-50E, as SPO2 detector is used for a measurement device. SPO2 performance upgrade was realized by installing hardware module XBee PRO S2B in the function of router-end device working mode. Except for ZigBee wireless transmission technology, it leaves a possibility to expand with Bluetooth module. The technical description is strictly related to the location of the patients using the GPS signal when it comes to undesirable measuring sizes of each decentralized measuring device. Possibilities to measure beats per second (b/s) is also included in the measurement device for saturation of peripheral oxygen. Smart city integration is part of upgraded hardware which operates on the level of hospital cloud. With existing smart city infrastructure, it is easier to connect mobile IoT (Internet of Things) logger of ECG and SPO2 measurements. This article describes only the main reasons for chest pain. Acute and chronic chest pain is defined with ECG signal waveforms in certain cases. Measuring graphs are based on 12 measurement points that lead to the electrocardiogram device.

## KEY WORDS

mobile ECG/SPO2, chest pain, WSN, GPS, smart cities

## CLASSIFICATION

JEL: Q53, R41

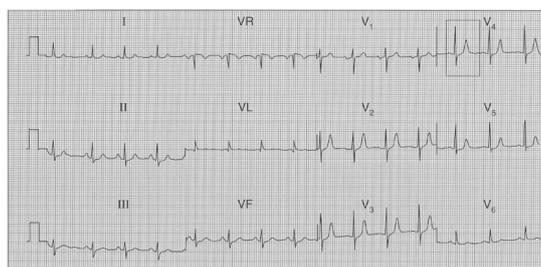
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## INTRODUCTION

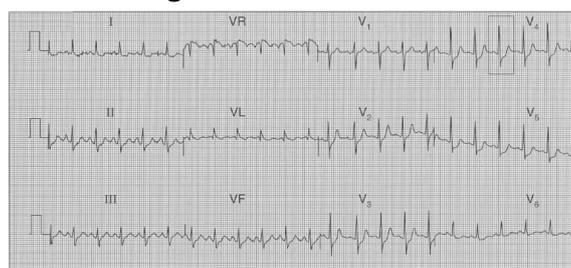
Subjective indicators are usually related to electrolyte abnormalities of ECG. Abnormalities of the plasma levels of potassium, calcium, and magnesium affect the ECG, while changes do not affect the plasma sodium level. The T wave and QT interval (measured from the onset of the QRS complex to the end of the T wave) are most commonly affected. A low potassium level causes a T wave called U wave. A high potassium level causes peaked T waves with the disappearance of the ST segment. The QRS complex may be widened. The effects of abnormal magnesium levels are similar. Low plasma calcium level causes prolongation of the QT interval, and high plasma calcium level shortens it. Nonspecific changes are coherent also with the ST segment. T wave flattening or peaking with an unusually long or short QT interval may be due to electrolyte abnormalities, but many minor ST-T changes are nonspecific like NSTEMI.

Methods for measuring ECG signals are based on the n-numbers of leads. Increasing the number of leads, the quality of the signal as a reduction of outliers is proportional. Throughout this article is used 3-leads development measurement system, while the concept of an example method uses 6-12 leads [1]. Method with three leads represents two points of the measurement signals and the third point of reference potential [2]. Measurement method with 6-leads of measuring points is defined with abbreviation: I., II., III., VF., VR. and VL. The measuring method with 12-leads includes all the above-mentioned points with the addition of V1 to V6 abbreviations. Except for defined measuring points, it is important to know that specific summation of primary dislocated points on specific body area are an integral part of virtually treated signals like an LA (left arm), RA (right arm), LL (left leg) [2]. The measuring graph is defined with millimeter paper on which one millimeter represents 50 ms. Observing the inflection point of each QRS wave is defined with a 1s interval.

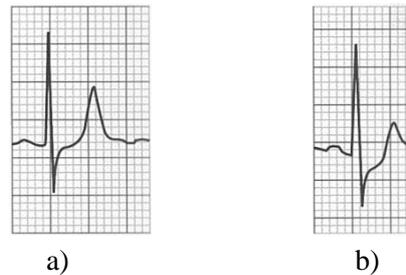
Presented case of the normal ECG signals with sinus rhythm and the QRS complexes; Figure 1 shows possibilities of minimal ST-segment depression in lead V5. The calculated time heart rate is 60 beats/min. A detail from Figure 1 is described in Figure 3 a) and represents a normal ST segment in lead V4. Example [2] of exercise-induced ST-segment depression is described on the same patient as in Figure 1 but now with ST-segment depression which slopes upwards, Figure 2. Detail from Figure 2 represents the suspicious change in lead V5 but without diagnostic of ischemia, Figure 3 b).



**Figure 1.** Normal ECG.



**Figure 2.** Exercise-induced ST segment depression.

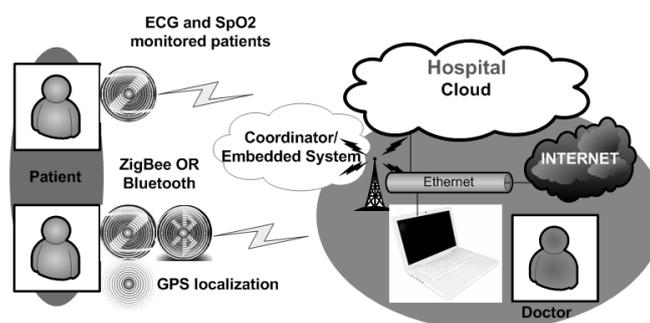


**Figure 3.** a) Normal ST segment in lead V4, b) Upward-sloping ST segment depression in lead V4.

## MONITORING SYSTEM AND WIRELESS DATA DISTRIBUTION

The main concept idea of the prototype is to reassemble all available embedded devices from the biomedical-electronic area and summarize quality signals for the unique alarming system. The used device is developed break board for measuring ECG signal with 3-leads and SPO2 wired online monitoring device with beats/min. Extra display on the SPO2 device provides a recordable photoplethysmograph. Standard wired SPO2 is upgraded to ZigBee (XBee PRO S2B) and second wireless option cross Bluetooth [3, 4] wireless transmission media. A practical example (Figures 1, 2 and 3) shows better performance of measured signals because is used the 12-leads measuring system. A combination of 3-leads ECG wireless monitoring signals and upgradable SPO2 is a cost-effective solution for the alarming of dispatcher doctor, Figure 4. An alarming signal is mostly routed on the synchronization of ECG (ECG development board) and beats/min. which is integrated on SpO2. Except for monitoring these two sensors, the important measured value is PPG [5-9]. During the measurements, SPO2 system shows a graph with a specific function. Slope PPG function describes the alarming level of actuator operation. The main reference for alarming dispatcher doctor and activation of GPS circuitry for the location of the patient is the PPG slope function. A large function slope means that oxygen content is decreased and patient health is in danger. GPS location of a patient with the developed device set with mobile ECG and SPO2 cross ZigBee and Bluetooth wireless technology is presented thought block diagram of monitoring infrastructure in Figure 4. The data storage solution is a standard cloud or device cloud with an embedded distributed coordinator system [2, 10-12]. With this scenario, intranet and internet access for dispatcher doctor is available and configurable.

The data transmitting range is limited on distance of ZigBee and Bluetooth devices which is 300-1600 m, theoretically. Hospital areas can be interpreted as a wide working area of wireless embedded devices with cost-effective energy consumption properties. Bluetooth networking, in this case, should be used for small clinical areas and designed to work in ad/hoc mode. Depending on the network topology, ZigBee with a small speed rate at maximal 250 kbps satisfies requirements for data transmission. These networks can work in router/end-device mode. Network media access itself is extensible in comparison to the number



**Figure 4.** System monitoring infrastructure.

of wireless nodes. Locally, in hospital areas, it can be created a low latency network with even higher density coverage of ZigBee coordinators. Such a priority mode in subnetwork can bring this alarming status of the patient to a higher level of interaction. A hospital cloud system can be always separated later on when a patient is under observation. That means that IoT measuring device ID is just migrating from hospital to smart cities network. The application layer stays the same while the transportation layer is changing in a way of different “room”. Since the SPO2 measuring device has significantly bigger power consumption it is considered to use sequences of measurements while patients are in smart cities environment.

## MOBILE ECG AND SPO2 (OXIMETER) DEVICES

Mobile ECG is created on a development board with a long-range ZigBee module, Figure 5 [13]. The same wireless module is used for SPO2 device and data content is transmitted through the serial port interface. RS232 port on the ZigBee module for ECG is used for GPS NMEA protocol. Measurements of the ECG curve and QRS complex are realized through the ADC input of the module. Multiplication of ADC and serial data was processed in the Freescale processor on the XBee PRO module. Coordinator module with parsing data deploys vector “raw” information to the hospital database cloud. Active electronic is designed to work on 3,3 V, the same voltage level as a module. With the same voltage level for power supply of filter and amplifier chipset, the developed set is compatible device unit. Instrumentation amplifier AD623 can operate on a single supply voltage. Reference voltage for other circuitry is provided by 1,2 V from the MAX6120 chip. Integrated series parts of filters are OpAmps OPA237 which work on the voltage level of 1,2 V. The small dimension of the developer board is possible to put in the box with battery power supply and lead connectors. To gain a higher range it’s possible to use embedded XBee PRO S2B module with RPSMA connector. Bluetooth integration necessary requires the implementation of a pre-programmed microcontroller with quality ADC conversion and serial channel. A graphical interface is created in the LabView development software tool. Programming in a graphical block diagram is represented in Figure 6. The existing solution of data collection is created for XBee Series 2, while in this case is adapted for formatting data string and fragmentation of packet for XBee PRO S2B.

A measured variable in the block diagram is multiplied with a reference voltage (3,3 V) and divided with 1023 because the ADC of the module is 10bit level distribution. Local analytics is manifested through a graphical interface compiled from LabView front panel, Figure 7. Data extension from Coordinator/Embedded System to local or external cloud services is realized with LabView Network Tools kit, Figure 4. The existing library for a specific protocol (TCP/IP, UDP, etc.) is integrated into the kit module with covered standardization. ZigBee module has RS232 interface and with GPS receiver NMEA protocol is received on

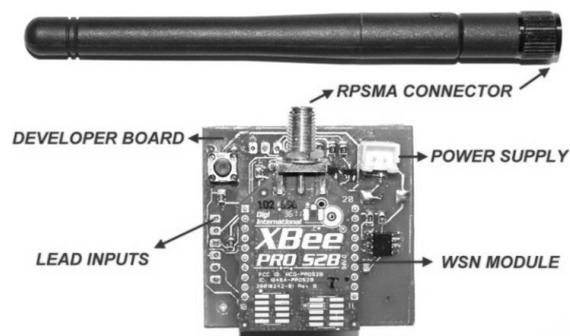


Figure 5. ECG developer board [13].

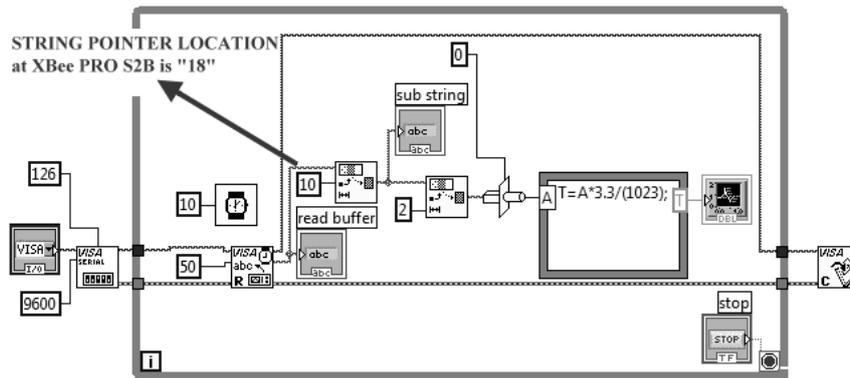


Figure 6. Adaptation of “G” code in block diagram for XBee PRO S2B module [13].

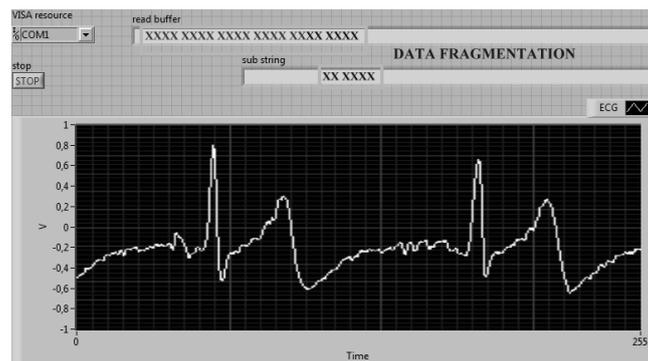


Figure 7. ECG local logging application (front panel) [13].

the same transmission media channel. In this case, is used another “G” code in LabView with alarm manifests. This kind of interrupt On\_Serial\_Rx activates remotely dislocated browser with GoogleMaps and displays patient location. Thus, in a very quick way is possible to locate and ensure patients with a supposed diagnosis of chest pain.

Pulse oximetry is known as a non-invasive method for monitoring the level of oxygen in the blood. SPO2 measurements are based on successively skin illuminated red and infrared light beams. During skin exposure to modulated frequency of red and infrared light density of oxygen is represented like varying variables [14-16]. The wavelength of the light sources used for the measurement of the SPO2 and PPG is 660 nm and 890 nm. For filtering artifacts and elimination of the hand movement drift on measured signal its used passive filter for elimination of unwanted harmonics and offset reduction. Oximetry is usually intended for measurement on a specific point on the body area. Such an area of points is with many blood circulation in the capillaries like earlap or finger [16, 17].

Purchased SPO2 has later added, integrated Kalman filter and therefore, there was no need for integration and installation of additional electronic or software filters, Figure 8. Kalman filter is used for the quality resolution of data [18]. Utilization is focused on the measurements of a very rapid heart rate where the beats/min. is high. Such cases are in newborns children up to 5 months because they have a high beat rate per minute [19]. An average number of beats/min at newborns children is from 90 to 140 beats/min, while at middle-aged persons is from 60 to 90 beats/min. Oxygen saturation (SPO2) is defined as the ratio of oxyhemoglobin to the total concentration of hemoglobin present in the blood [20]. Also, PPG is a very important value for normal heart rate function detection [7, 8, 21-25]. PPG is part of the complete image of the patient which covers relationships among PPG, PVC (Premature Ventricular Contraction), BP (Blood Pressure), and ECG [26, 27]. Exposition to an irregular operation usually is caused by a rough measurement error like low blood perfusion, dirty sensors or LED lights and improperly position on the oximeter. A frequent reason for

the error is the movement of the body parts known as an artifact. Detection of weak heart signal in the PPG graph is the main reason for alarming as a long artifact disposes of. Except for long exposure to artifact influence, the system is sensitive on continuous weak signal. Measured PPG is relevant data for alarm activation and GPS sending data for the location of patients when health is in danger. If SPO2 percentage or ratio of oxyhemoglobin in a total concentration of hemoglobin in blood is less than manually set up value (default is 85), an internal alarm on a device is activated. This information can alert the patient and detect health status half an hour before the occurrence in the case of a heart attack or cardiac arrest.

A pulse oximeter (SPO2) with PPG for logging data using USB adapter cable for communication with PC. The oximeter device, in this case, is not a USB host controller then just standard “slave” device and because of this adapter is necessary for bridging data. The default adapter is designed on the base of C51 (8051) architecture and works on the principle of the virtual serial port. Usually used the chips for this purpose are PL2303 and FTD232, while FTD232 has better hardware properties in operation. The main difference between default adapter and mentioned adapters is protocol integration in preprogrammed C51 microcontroller. USB mini B connector on the oximeter device is not a hardware compatible pinout for USB. Power supply line (5 V and GND) are compatible with USB mini B connector, while default D+ and D- pin is repurposed to 3,3 V TX and RX communication lines. Addon and communication configuration is realized by bringing the standard vector “raw” data of asynchronous serial packets. In this way parsing of data is done on the Coordinator/Embedded System side and its ready for deployment to cloud. Wireless transmission media is also XBee PRO S2B module with a serial channel. These two channels can be separated with an ECG device or these two devices can use serial multiplexers on single transmission media which means a shared transportation layer.

From a technical perspective to medical calculations hemoglobin molecule can carry a maximum of four oxygen molecules. Thousand hemoglobin molecules can carry a maximum of 4 000 oxygen molecules; if they together were carrying 3 600 oxygen molecules, then the oxygen saturation level would be  $(3920/4000) \cdot 100 = 98\%$ , Figure 8 [27]. The standard value of SPO2 at a normal heart rate is from 95 to 99%.

Application for measurement and local data storage is used for serial protocol understanding and creation of packet parser. Real-time measurements are available on default installed application with all three parameters, Figure 9. Offline analytics is available in the review application, Figure 10. Logging data on local data storage is editable by any statistic program. During measurement application can create simultaneous three files; \*.spo and two \*.csv. Extension \*.spo is for review application, while \*.csv represent format; SPO2, “PULSE” (e.g. 98, “66”). Separated \*.csv file content of single value in the time domain, PPG Figure 11.

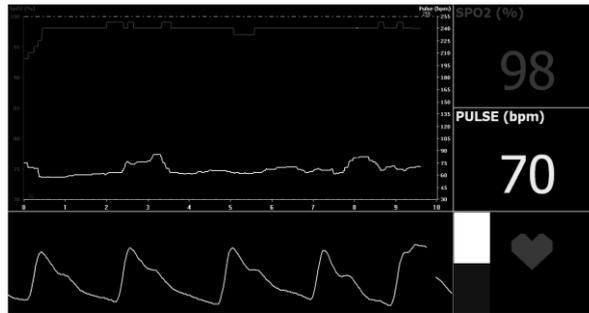
The recorded scenario shown in Figure 9 and Figure 10 represents two periods of high interrupt pulse rate. This scenario is accompanied by a change of SPO2 value as artifacts in the PPG graph. Normalized PPG graph in periods without interrupts symmetrically follow standardized function curve Figure 11. Ordinate values distribution shows scaled AC on offset area and represent curve characteristic on finger measurement. Different curve characteristics of function are defined with other parts of measurement points on the body [17, 28].

## **SUBJECTIVE INDICATORS OF CHEST PAIN BASED ON MEASURED SIGNALS**

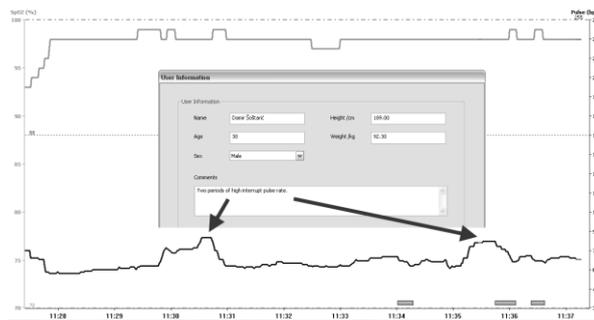
Measured signals, such as the ECG system with 3-leads and accompanied by the early mentioned scenarios with 6-12 lead is a sufficient indicator of the irregularity of heart function. Measurement examples with normal ECG waveform or curve and QRS wave in leads



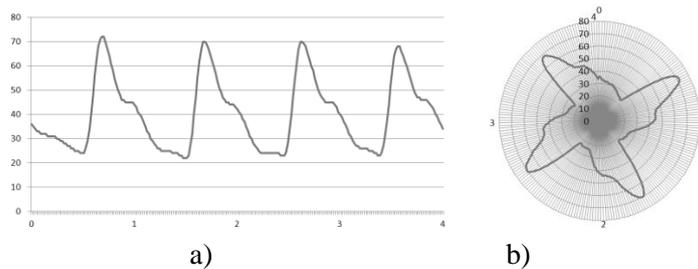
**Figure 8.** SPO2 (Pulse Oximeter) with PPG.



**Figure 9.** Application view of SPO2, pulse rate and PPG.



**Figure 10.** SPO2 and pulse rate.

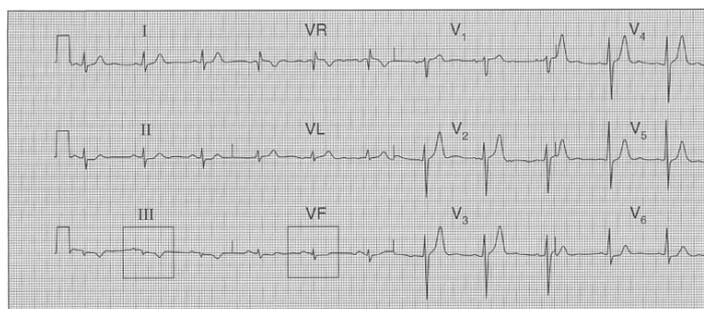


**Figure 11.** PPG a) standard, and b) polar view.

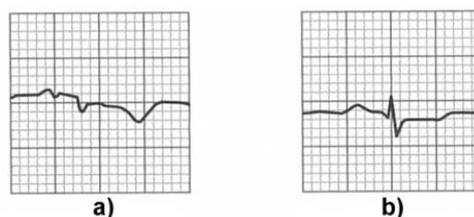
define very small irregularities in heartbeat. Embedded developed ECG board with three leads is created for sending of an alarm signal. Such a system meets the standards in wireless aspects on the highlighted cost-effective solution. Based on a variety of biological functions, system detection is focused on artifacts elimination of irregularities and achieve better performances of the device. Upgraded oximeter on wireless media has three basic measurements, SPO2 (%), pulse heart rate (bpm) and PPG. A combination of all four signals and synchronization of databases in the hospital cloud system can alert a doctor on duty. Except for four basic data signals, the doctor receives a sequence of NMEA protocol from GPS and it's capable to locate a patient on Google Maps in a few seconds. Subjective indicator of chest pain is precisely defined with the basic four embedded signals of which primary ECG signal can be predicted half an hour before the patient could have a heart attack.

## CHEST PAIN HISTORY AND EXAMINATION

There are many causes of chest pain. All the non-cardiac conditions can mimic a myocardial infarction, and so the ECG can be extremely useful when we making a diagnosis. ECG is less important than the history and physical examination because ECG can be normal in the first few hours of myocardial infarction, Figure 12 [1, 29-31]. Details from Figure 12 are enlarged in Figure 13. At first glance it seems that everything is ok; sinus rhythm, normal axis, normal QRS complex, ST probably normal, but T wave in lead III. and flattened T wave in lead VF are indicators of small irregularity.



**Figure 12.** Nonspecific ST segment/T wave changes.



**Figure 13.** a) Inverted T wave in lead III, b) Flattened T wave in lead VF.

Chest pain can be divided into acute and chronic. Acute chest pain features are divided on; myocardial infarction, pulmonary embolism, other lung diseases, pericardial pain, aortic dissection, esophageal rupture, spinal pain, and shingles. Chronic chest pain usually is intermingling with angina. The main marker of insulation is a commonly middle-age person. This pain is called *atypical chest pain* with an implication of cardiac ischemia but symptoms are atypical. History indices of angina diagnosis are that the pain is; predictable, induced by emotional stress, relieved by rest.

## GPS LOCATION OF THE PATIENT AS A PART OF SMART CITY GRID

The location of the patient has been realized with a GPS receiver; “ublox LEA6S” which is compact size, Figure 14. The main advantage is low power consumption and a very fast start. With active GPS and antenna integration, generally is a reduced area for installation in a small box with other monitoring devices. High receive sensitivity enabling us for more satellites and higher precision. The embedded GPS device has a USB connection and an RS232 serial port. NMEA protocol transmitted data with a serial channel is forwarded on Freescale microcontroller in raw format. Accepted data are sent directly to the ZigBee wireless transmission medium on the transport layer. For indoor localizing systems, indoor localization can be done with RSSI signal component of the XBee module [32-35]. The outdoor principle was designed for near-field or short-range of hospital surroundings. Except for hospitals, this system is designed also for home use where user can be connected and registered at home while using private network connection or smart cities infrastructure. When a device is used locally at-home patient has to have a special attached router/gateway on a home network.

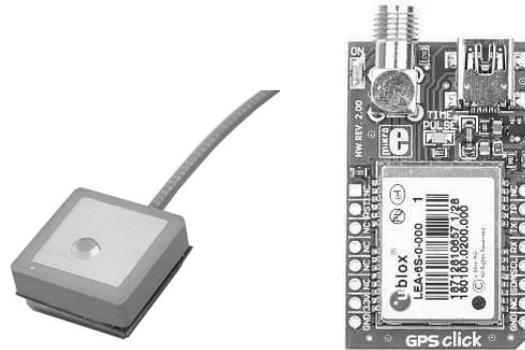


Figure 14. Module of GPS active antenna and receiver.

## CONCLUSION

Subjective indicators of chest pain are based on observed measured signals. With only one measured parameter it is possible to detect irregularities of heart rate or to predict a heart attack. The primary measured ECG signal allows us to alarm the doctor if it comes to irregular QRS complexes or ECG waveform. Except for this set of integrated embedded wireless devices for future work on monitoring is considered blood pressure. Measurement of blood pressure with the differential method using interference of two or more light sources is considered. Instead of 3-leads, future work is focused on 6-12 leads based on the Android/iOS platform of an embedded system with ADC multiplication of channels. Such an application is considered to work under a “room” environment where the application level is defined priority. With IoT “room” declaration, ID should be registered on a specific infrastructure, e.g., hospital, home or directly on smart cities. Depending on the case scenario of network infrastructure, future work is to use blockchain technology with different blockchains for each case of infrastructure. In that case, a cloud system can be eliminated because all data are safe and forever written in the chain [36].

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# SUBJECTIVITY AND TECHNOLOGY IN WORK OF TECHNICIANS IN PERIODICAL TECHNICAL INSPECTION STATIONS

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## ABSTRACT

The article deals with the subjectivity-technology theme and is based on qualitative study of technologically highly mediated technicians' work in two stations for periodical technical inspection of vehicles in Croatia. Specifically, it is studied how supervisors for periodical technical inspection of vehicles interpret the place and importance of their subjective judgements in contrast to technologically driven advancement of devices they use in everyday work activities. The main concepts guiding the analysis stems from the organizational research on work and technology according to which human beings act toward things on the basis of the meanings that things have for them. Other concepts included structural aspect of technicians' professional identity and work autonomy, organizational contingencies and social interactions as integral part of technical work.

Four descriptively based themes emerged through the procedure of summing up the findings. They suggest strong and enduring intertwining of human factor and technology in contingent organizational context. Findings suggest that subjective judgements are regarded as necessary human activity permanently related to simultaneous use of devices in the process of inspection where recognizing complex task related appearances, and spotting unusual events are integral part of work. Finally, interactional patterns suggested communications as the integral part of the job, often as the most difficult, stressful but simultaneously indispensable condition for work to be done correctly.

## KEY WORDS

subjective judgements, devices, technicians, communications

## CLASSIFICATION

JEL: L84

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## INTRODUCTION

Contemporary and upcoming technologies significantly mediate the changes in the character of human work and in the activities of organizations in which this work takes place. In media and public discourse this subject is considered simultaneously in terms of great expectations and potential threats with regard to broader societal implications of ever faster technological development, most notably for the future of employment and new jobs, skills needed in the upcoming world of work and for a character of the new forms of organizations [1]. Regardless of whether technology is conceptualized in narrower or broader way, “work scholars have long debated the impact of technological development on work organization” in similar, mostly binary-type narratives approaching technology at work predominantly in positive or negative terms [2]. A corresponding conceptual binary tension is possible to identify in the longstanding discussions between the technological determinist and the social constructivist perspectives on technology, two approaches which differed mostly in assessment of possibility and the scope of technology to determine the pace and content of social change [1].

At an organizational level, the relationship between work and technology has been analysed and conceptualized almost constantly in a more nuanced way due to empirically based insights which highlighted the contingent nature of work-technology issue in particular organizations that have been studied. Generally, their findings and conclusions vary considerably depending on the specific issues they dealt with, the theoretical perspectives on which they are based, as well as on the applied research methods [3]. Research questions mainly focused on how existing and new technologies mediate work autonomy, discretion, skills and work experience, as well as social implications associated with the ways of introducing and applying them. In the relevant literature it is possible to discern several attempts to systematize the most significant researches, usually through pointing to several “generations” [4], paradigms [1] or theoretical approaches [3] that marked the research development in the field of work and technology at the organizational level. For the purposes of the present article, it is sufficient to remark that in the greater number of these systematizations common point suggests that the interpretivist approach which has focused on “local meanings” [5] with the avoidance of unnecessary generalizations prevailed since 1990s [4].

However, it is possible to claim that contingencies emerge earlier, already in maybe the most canonic studies unavoidable in corresponding literature. For example, Blauner in *Alienation and Freedom* pointed to technology as the main factor which determines workers’ experience of work. However, Blauner confined this influence with regard to structural differentiations related to actual use of particular technology and with regard to particular organizational forms related to the internal division of labour [6]. A couple decades later, Zuboff studied a number of manufacturing and service organizations which were introducing information technologies. Although emergent computer technologies were observed as an unavoidable element of future workplaces, Zuboff left a room for divergent alternatives for work and power depending on the ways in which such technologies were considered and used in particular organizations. In the computerized organizational context Zuboff found out a kind of intertwining of technology as an essential feature of work and “the matters of choice” – or ways in which managers would decide to use it [7]. Zuboff implied that “information technology contains a duality that allows companies to automate or informate” [1], i.e., to reproduce old hierarchical divisions between workers and managers or to enhance the new culture of discussion, collaboration, meaning of work and to undermine existing organizational hierarchies.

More recently, Liker, Haddad and Karlin [3] summarized a number of factors related to the contingent nature of work-technology relationship at an organizational level. The authors referred to factors such as types of technology, intraorganizational social contexts, scopes of participation in the selection of technology, and structural consequences of technological change (who wins and who loses). While indicating the importance of theoretical approaches in the assessment of these contingent factors, the authors synthesized some major perspectives, including interpretivist approach which we found the most referent for our study because it “leads largely to descriptive and analytic research that provides a rich picture of the process of technological change” [3; p.586].

Most of interpretivist approaches to work-technology issue in organizations are focused on the study of human meaning as a guiding point for understanding of corresponding everyday actions. Therefore, organizational events and objects like devices and other technological artefacts which have arisen in their customary use are not comprehended as entities with intrinsic meanings and cannot be separated “from the meanings people assign them in the course of everyday social interaction” [5; 1404]. More or less explicitly, these approaches rely on broader sociological tradition of symbolic interactionism and its relativisation of the conventional image of reality as purely external and independent of our actions. Correspondingly, different aspects of human behaviour could not be determined according to an abstract and in advance defined person’s “nature”. Quite to the contrary, human self-identification and social action represent the outcome of continuous mutual defining and communication in the process of social interaction [8].

These theoretical backgrounds are also recognizable in other research on work-technology issues in organizations. On these grounds Prasad documented multiple symbols associated with computerization in the health medical organization she studied for extended period, suggesting at the same time that “computerization, or any technology can simultaneously hold different meaning for individuals or groups in organizations” [5; p.1422]. Barley, in his study of introduction of CT scanner technologies in two hospitals found varying degrees of empowering effect these technologies had on technicians’ work, allowing them to interpret the data much more autonomously and to make judgements previously left to professionals [9]. Technicians are in focus in other Barley’s researches in which he proposed contextually derived model of technicians’ work. Since it was found that the technicians’ work consists of bridging the material and the world of representations through the use of sophisticated instruments, techniques and bodies of knowledge, Barley has proposed new and necessary rethinking of organizational restructuring with regard to notions of horizontal organising and professionalism [10-12].

Darr and Scarselletta also proposed the concept of technicians’ identity based on Goffman’s suggestions that everyday interaction should be analysed with regard to broader structures which are more or less usually hidden behind actual everyday events. Analytically, this would lead to the integration of interactional dynamics of technical work with patterned, i.e., “framed” and structured organizational characteristics [13]. In organizational settings, technicians mediate between the transformation of the material realm into symbolic representations and their structured interactions with professionals and clients. Still, Darr and Scarselletta are cautious about broader generalizations on the nature of technicians’ work and identity since the differences tend to appear with regard to a variety of technical occupations, knowledge bases built around different technologies and the scope of autonomy in everyday work. Summarising the findings from several ethnographic studies, Darr and Scarselletta point to the role of technology as the main factor in the process of technicians’ identity formation which tend to change when interaction with clients is introduced. Although contextually developed and technologically driven technicians’ knowledge base allowed for self notions of competency and good work, communications with clients indicated that this “identity formation takes on a subtler shading” [13; p.72].

Communications with clients and coworkers has also been a conceptual component in Trevelyan's attempt to reconstruct engineering conduct from practice. Drawing on the findings from different organizational settings and a semistructured interviews Trevelyan pointed to a common practice among engineers to frame their identity predominantly "in terms of the solitary technical: problem-solving and design" [14; p.176] with a tendency to "hide the social dimension of their work behind a technical facade, and, in doing so, [to] marginalize important aspects of their work" [14; p.173]. On the contrary, Trevelyan's analysis reveals that engineering practice is essentially based on distributed expertise which is derived from the shared meanings constructed in everyday interactions among engineers themselves. This finding allows Trevelyan to conceptually establish human performance and social interactions as integral part of any engineering conduct and to grasp them as elements which "lie at the core and constrain engineering outcomes just as material properties constrain the feasible height of buildings" [14; p.190].

The present study also aims at the micro level of the technology-people-organization subject theme. Specifically, we consider how periodical technical inspection supervisors – PTI supervisors hereinafter – (mostly technicians) at two selected periodical technical inspection stations (PTIs) interpret the place and importance of their subjective judgements in contrast to technologically driven advancement of devices they use in everyday work activities. Since the equipment which has been used by the supervisors at studied PTIs turned out to be constantly upgraded with the main current changes established in digitalisation of some existing devices (like the introduction of RFID cards for reading and recording of needed data), we rely on Tornatzky & Fleischer's definition of technology as "knowledge-derived tools, artefacts, and devices by which people extend and interact with their environment" [15; p.11]. In this regard, human characteristics seem to be important in recognizing complex task related appearances, spotting unusual and unexpected events, adjusting the decision-making process to different situations and in ability to make subjective judgments and decisions [16].

Additionally, the article presents several findings on issues which were not planned by initial research design and which emerged along the fieldwork and semistructured interviews with supervisors. These issues are considered in terms of the main themes PTI supervisors highlighted with regard to their experience of work. Given that the research has been qualitative with interpretivist features, we considered such a sort of open-ended flow of the study not only legitimate, but also instructive [17]. That means we entered into research with an approximate theoretical framework on technology-people-organization, but have had to relate unplanned findings to concepts we were looking for along the research itself.

## **RESEARCH DESIGN AND PROCEDURES**

The findings are collected through field notes and data from mutual conversations and interviews with PTI supervisors at two periodical technical inspection stations (hereinafter, PTI stations) in Croatia. One of the authors, while working for one year in one of the stations as a PTI inspector, initiated the idea of exploring subjective judgements in vehicle inspection. Options for the realization of idea began to be realized immediately after she moved to another position in the same company. Since the possibility of collecting notes from long-term fieldwork was discontinued, several mutual – recorded and later transcribed – conversations were held. In these conversations, a series of issues related to the most diverse vehicle inspection details were discussed, such as moments in which subjective assessments appear as possible or necessary; interacting details and ways of dealing in such situations; and information about the company and its organizational structure.

Several items important for continued research were indicated at this stage. First, it was clearly explicated that consideration should be given to the reflexive dimension of the

research since all our discussions included a certain interpretations which are related to the basic topic of the research [18]. Second, in the absence of the opportunity to undertake longer field participation, we agreed to conduct joint field observations through ten occasions in both stations over a two-month period. Third, it was found that for the continuation of research, it was necessary to conduct semi-structured interviews with the PTI supervisors in the two stations where the company provided us with access.

The inspector's involvement was completely voluntary, they were provided with anonymity and with real and fully elaborated opportunity to not answer or discuss issues they regard confidential or in any way unwanted and to leave interview at any time they find it disturbing. During the interviews, a part of the inspector indicated that the questions about cheating on the examinations would most likely be avoided, while the rest of them spoke about this subject generally, with the suggestions that ethically problematic situations happen "somewhere else". In our kindly effort to consider these topics in more detail, they also expressed the desire not to talk about it anymore. Therefore, we did not insist on this topic because this would be unethical on our side, regardless of our stance that the topic is important and multilayered for the research of work of the PTI supervisors. In the case of such a study, it would be necessary to shape the theme of ethics either as an integral part of wider research or as a separate research focus and to communicate it transparently to participants who would like to talk about it. Therefore, regardless of the fact that it was occasionally touched in some discussions, the topic of ethics did not represent the relevant material for later analysis of the obtained data. It is interesting that a number of our colleagues who commented that our decisions in that matter represent an important deficiency, claimed they "heard" something about cheating from "someone else" and never experienced it by themselves. It turns out that all of them – supervisors and our colleagues – consider that topic in relatively similar terms with prevailing expressions like "someone else" and "somewhere else" suggesting no-one directly involved, be it PTI inspector or scientist-client.

Ten PTI supervisors agreed to participate in the interviews. Analytically, a basic doubt, well known in qualitative researches and related to the character of credibility based on a relatively small sample, emerged. Generally, sample size estimates in qualitative research range from only few and less than ten to over fifty participants [17]. We found that in a number of qualitative studies we had opportunity to consult for a range of reasons, a similar sample size has been used sometimes purposively, but sometimes without clear evaluation [19-21]. In the present study, it was estimated that our participants represent relatively homogenous group with the same education, working the same job, and they were all male. In addition, possibilities of triangulation here included our aforementioned conversations and field observations. Nevertheless, we conducted interviews with the intention to consider whether an onset of saturation of one or more elements that could be formulated in some interpretative form will emerge and whether we can find the possibilities for describing the interactional elements that can be related to some of the concepts developed in other researches.

Interview protocol consisted of few broad, general questions related to single research focus on technology-subjectivity topics. These were followed by a number of more specific and detailed questions. However, during the interviews, other and initially unplanned topics were arising and when estimated as relevant were included in next interviews. For example, communications with clients (vehicle owners) were constantly indicated as potentially important element in actual social interactions related to work content. Every interview lasted about one hour. All interviews were recorded and transcribed.

Analysis followed standard qualitative analysis techniques [22, 23] and included triangulation with regard to our initial conversations and the notes from field observations. It started with repeated listening of recordings and reading the transcripts in order to indicate significant

statements, sentences, or quotes we regarded helpful for understanding and later construction of more concise meaning units or themes of description of participants' experience related to technology and other aspects of work [17].

## **RESEARCH SITE**

The research was conducted in two periodical technical inspection stations (PTIs) in Croatia. The first PTI station – PTIs 1 has four technological lines, the first two for light vehicle inspection and the other two for heavy vehicle inspection. It employs 17 employees, from which nine perform technical inspection of vehicles and are therefore called PTI supervisors. The second PTI station – PTIs 2 has two technological lines and is mostly inspecting light vehicles. The number of employees is 22, where 12 of them are PTI supervisors. Considering equipment and devices that are being used during an inspection in both PTIs, there is no great difference between them, apart from their layout on the testing line and different type of their manufacturer. In addition, PTIs 2 was relocated and renewed. The main difference between them is in the average age of inspected vehicles, which in PTIs 1 is 8,55 years and 12,59 years in PTIs 2. During the research the experimental testing, which uses modern RFID technology, was used in the process of vehicle inspection in PTIs 1 and it was not used in PTIs 2. However, when conducting the interviews, both PTI stations were using it. The purpose of that experimental testing was to reduce the probability of manipulation with data that are manually being collected during periodical technical inspection of vehicles and human factor regarding work ethics and subjectivity as well.

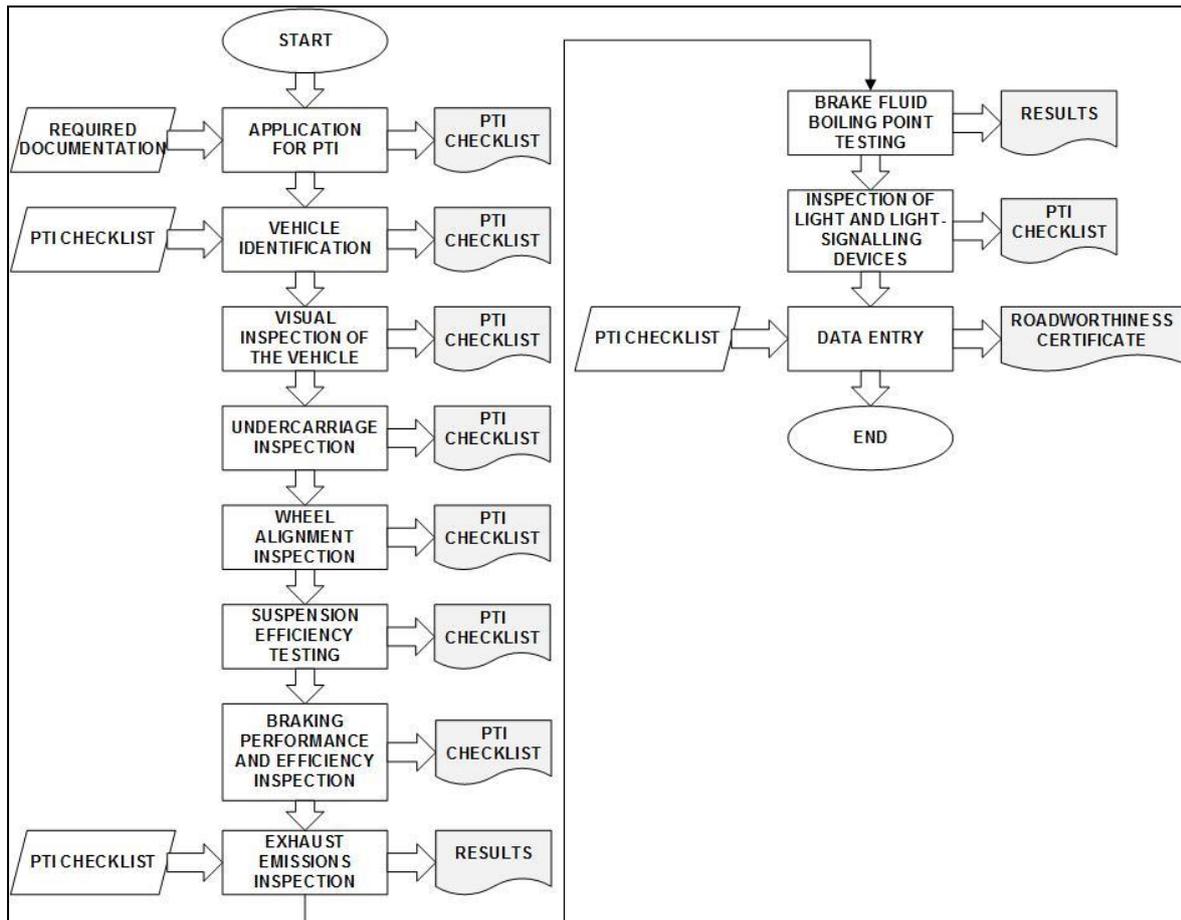
Technical inspection includes several steps and procedures. Preferably, the vehicle that is going to be inspected should be clean and tidy. The legal regulation prescribes devices, equipment and assemblies, possible defects on them and their categorization to be checked during technical inspection. It includes as follows: identification of the vehicle, steering, braking equipment, lamps, reflectors and signalisation, visibility, chassis and chassis attachments, axes, wheels, tyres and suspension, motor, nuisance, electrical equipment and installations, gear transmission, control and signalling devices, exhaust gas examination of motor vehicles, other devices and parts of vehicles, other equipment, supplementary tests for passenger-carrying vehicles categories M2, M3 and gas installation.

According to EU Directive on periodic roadworthiness tests for motor vehicles [24], deficiencies that are found during periodic inspection of vehicles can be classified as minor, major or dangerous. Minor deficiencies have no significant effect on the vehicle safety or impact on the environment. Major deficiencies may prejudice the safety of the vehicle or have an impact on the environment or put other road users at risk. Dangerous deficiencies represent a direct and immediate risk to road safety or have an impact on the environment and can therefore be prohibited for use on public roads.

It is difficult to compare PTI stations in Croatia because they differ in their size, number, length and width of testing lines, allocation of the various equipment and devices on them, employee number, etc. That variety is the main reason why there is no standardization of inspection procedure and therefore represents a big challenge regarding process improvement. Hence, it is difficult to represent testing procedure by using a flow chart. However, in order to show which activities are included in the testing procedure, the Figure 1 represents one example of PTI station and its layout regarding sequence of activities.

## **FINDINGS**

Altogether, 59 differently-defined codes emerged that are initially systematized in 11 formulations which indicated relatively rounded meaning sets related to subjectivity- technology



**Figure 1.** Example of PTI station and its layout regarding sequence of activities.

research question and to topics which were unfolded in the course of the research. These formulations were further classified into 4 distinctive themes, Table 1.

The first theme refers to patterns in assessing vehicles' roadworthiness, regardless of whether they are subjective or are based on devices, and to patterns that reflect not only explicit but also tacit knowledge based on supervisors' previous mechanical experience. The second theme refers to the supervisors' patterns of activity in unclear situations, which arise from uncertainty in their own judgments during the examination of certain parts of vehicles, or from questioning the initial perceptions, or are mediated by confusing aspects of getting or interpreting data from the device. The third theme refers to how difficult is to make a judgement and, again, includes references to the importance of subjectivity and to the role attributed to devices. The fourth theme points to the key interactional patterns in the inspector's work.

Two codes appeared in most of the themes, Table 1. Both are meaningfully integrated into the final themes and are an integral element in the ways in which supervisors interpret the role and importance of their subjective judgments and judgments that are based on the use of different devices. As regards their ubiquity, they are presented here separately, irrespective of the fact that they can be discerned in the later elaboration of each theme.

The first of these codes refers to *senses*, which have repeatedly proved to be an important and unavoidable element in making subjective judgments; a possible source of unreliability of subjective estimates; and the way of checking and possibly confirming data from the devices. PTI supervisors have indicated that in most of these situations they rely on eyesight, hearing, smell and touch. In some parts of technical inspection such as a visual inspection, the corrosion

**Table 1.** Themes and omnipresent codes.

<b>Final themes</b>	<b>Preliminary themes</b>	<b>Omnipresent codes</b>
Assessing vehicles' roadworthiness	Subjective assessment as crucial. Devices as means for verification of subjective evaluations. Devices as the sole basis for evaluation. Mechanical experience.	Senses. "Is it valid or not".
Unclear situations	Subjective assessment as a source of uncertainty. Devices as a confusing factor. Mechanical experience.	Senses. "Is it valid or not".
Subjectivity and devices: difficulty of work	Subjectivity as the toughest part of the job. Devices facilitate and speed up the work. Devices are critical for assessment.	Senses. "Is it valid or not".
Interactional patterns	Communication with clients. Consulting with coworkers.	"Is it valid or not".

assessment or the assessment of the condition of the undercarriage senses are experienced as crucial and often the only indicator for making judgements and this is most commonly expressed in statements such as "there is no way for us to record the undercarriage, but only me who can see it and my hand to feel it" and "let's say, when you look at the undercarriage or estimate the corrosion, there is no technology ... I mean, you have to look there and to touch, you see, to be sure that you didn't miss something". On the other hand, supervisors indicated that the senses are not always an unambiguous indicator for making an assessment of the roadworthiness of a part of a vehicle, but they may be misleading and sometimes are an integral part of the confusing situations in which further checks are needed. One of supervisors clearly expressed this perspective: "Sometimes at eco-test ... my opinion is that the car, let's say, really does not have a proper mixture /of emissions/ ... somehow. But, when we insert the probe in the rear end, the device says it is okay. It means it happens that the nose deceives. Then I trust the device".

The importance of senses is highly saturated and was many times indicated in every interview. Although they mediate not only in strictly subjective judgements, but also in those which are based on data retrieved from devices, senses are, however, interpreted mostly as an indicator and element which suggests further checks. Generally, a corresponding role of senses was found by Barley's ethnography of technicians' work where senses were considered in terms of sensory-motor skills and presented as an integral part of contextual knowledge and point specifically to tactile skills which Harper called "ways of the hand" [10]. In the present research, they seem to be in a great part unconsciously integrated into cognitive processes when making judgements.

The second, it could be said the omnipresent, code is formulated *In Vivo* [25] and, due to the complexities in English translation, can be called *Is it valid or not*. Being saturated in terms of a dominant way of thinking and expressing the character of supervisors' work, this code has reflected the fact that they ultimately have to make a judgement, to literally decide, whether the car will pass technical inspection or not. Although supervisors indicated that their judgements are facilitated by the new rulebooks which allowed for greater range of

gradations in estimates on the validity of a part of a car or for broadening options to pass something, their final decision seems to be summed up in this simple formulation: is it valid or not. This code extends through all themes and represents the statement that is continuously, almost as the buzzword, repeated by all of them reflecting most poignantly supervisors' experience of work. All the nuances, all subjective judgements and all attitudes towards using devices, etc., are pouring into this kind of final assessment – the statement which is a typical example of dichotomy and which, although seemingly too rigid, summarizes all their activities. It represents the most important frame of reference for their sense of responsibility and, finally, creates a greater number of complications in their relationships with clients. That way, PTI supervisors express what they see as the essence of their job – they make the final decision on the overall condition of the vehicle and are not in the position of a number of technicians in other kinds of job which, regardless of (often unacknowledged or discredited) level of their expertise, only prepare or systematize data and leave such kind of decision to others (for example to scientists or professionals at higher levels of organizational hierarchies). PTI supervisors make decisions independently and autonomously and, that way, directly affect different outcomes for clients. To have possibility to grade or to “assign homework” to be done by clients until next inspection changes nothing.

### **ASSESSING VEHICLES' ROADWORTHINESS**

According to the findings, assessing vehicles' roadworthiness points to three elementary patterns in inspector's work. The first pattern refers to parts of the inspection in which judgments are entirely subjectively based. The second pattern points to the reality of a continuous combination of subjective judgments and the use of available devices, i.e., their parallel and simultaneous referentiality. The third pattern indicates a situation in which the devices are seen as the only frame of reference to judge and in which subjective judgments as reported by supervisors are not a relevant basis for making decisions. Basically, all three patterns are significantly permeated by the supervisors' mechanical experience.

In the preparatory phase of the research, we have assumed that parts of the examinations where the supervisors relate mainly to subjective judgments include vehicle identification, vehicle visual inspection, vehicle undercarriage control, and light control with regloscope. However, the supervisors pointed mainly to the importance of subjective judgments in the visual inspection of the vehicle and the chassis control, identifying them as parts of the inspection in which subjective judgment is of crucial importance and cannot currently be replaced by the use of a device. Two supervisors expressed this as follows:

“The ball, whether it's gone or not, I have to touch it with my hand. I have to take the tie rod end into my hand, see if it's valid or not. There is no such robot, there is no such machine that will come under the vehicle and here's the situation and now look what's wrong with it. Maybe it would be possible in some situations, but how complicated would this equipment be. You know, just how complicated the mounting and everything else would be. If it's possible to introduce it, I have no objections. To put something on the tie rod end, to have a machine check if there is something wrong with them, great. But as I say, I think that some of these things will not change. And of course, the optical inspection of the vehicle, I mean, it cannot, a machine, a device cannot do it.”

“For example, I would like to see how technology would estimate the corrosion down there. What is a structural one and what is only on the surface. I would like to see that, have someone to show me how that would look like.”

Other parts of the inspection where the subjective assessment was the only framework for making decisions on validity related to the colour, the exterior and interior appearances of the vehicle and so on. In all of the above mentioned sequences, the reliability of subjectivity is based on knowledge, mechanical experience, and sense of responsibility. While knowledge and mechanical experience usually refer to prior vocational education and to a number of years of supervisory work, here, in most cases, they are related to supervisors' mechanical family background and presupervisor professional biographies. For the most part, they were coming from families where someone, most often their father, had a mechanic shop, so getting to know the work of repairing vehicles represented an integral and even prevalent element in growing up and everyday life through which affinity to mechanical work and a strong sense of mechanic self-confidence had developed. This was also evident in other participants' statements which allowed us to recognize the image according to which subjective judgments have the force of objectivity in situations where the human factor is currently irreplaceable.

Nevertheless, when it comes to the bases of the judgments made, in many parts of the vehicle examination the subjectivity is interwoven with the use of the devices. Most commonly, participants referred to sequences of inspection process where previous and sometimes a certain subjective impression of roadworthiness of the vehicle was checked by connecting to devices and, thus, confirmed or refuted. These situations indicate that subjective judgment is constantly at work, it is present from beginning to the end of the inspection process, but although often indicates a roadmap for estimates, it has to be checked where devices are available. In those cases devices represent not only prescribed, but also internalized decision-making point of reference. One of the participants called this process the "symbiosis" of technology and subjectivity by clarifying:

“Specifically, if it is a braking system, it means that we are looking at the wear of the brake linings, for example, we are looking at the brake discs that can have this thickness. Let's say where it's not even prescribed how thick they have to be, but we're looking at whether it's burned, cracked or scorched on the surface by previous mistake. Then in a lot of cases when we get to the rollers later, we see exactly what we considered suspicious so to say. Here the device shows us the difference, helps us to make sure that, somehow, we estimated well.”

Finally, participants also described situations where they almost completely rely on devices. This suggests that in some parts of the inspection there is no need for a (subjective) assessment because it is contained in the data from the device. While it does not seem to be a complete ignorance or neglect of one's own involvement in such part of the inspection, it can be said that this represents a kind of “practical wisdom”, i.e., the belief that the devices serve to be used as reliable and competent aids in the work:

“When you enter the wheels into the rollers, it's normal for the apparatus to do its part of the job. That's it. Or when you measure the brake fluid, you will put a probe inside and it does its job. You push the button, you don't completely set your mind at ease, but you don't worry about it anymore. You will get the result, you print it and that is it”.

## **UNCLEAR SITUATIONS**

Unclear situations are interpreted by supervisors as an integral part of their work, as something that happens on a daily basis and is a result of a number of reasons, whether it is vehicle age, its current condition, hidden parts that need to be checked and inspected, details on certain parts that are difficult to assess, etc. Here as well exists the dichotomous

determinant in the background: supervisors cannot postpone or leave to someone else the decision on the validity or roadworthiness of a certain segment during vehicle inspection. Therefore, unclear situations imply increased attention and spending more time inspecting a certain part in order to make a responsible assessment of the problem at hand and not to make a mistake. They have to make the decision on their own and be certain that the decision is correct since its consequences are reflected in the way clients need to act from then on. Basically, supervisors associate main sources of uncertainty with self-questioning when it comes to their own subjective judgements, and with confusing data from the device.

In some situations, subjective judgements on a certain part of the inspection may vary between supervisors themselves and may be the subject of their disagreement. Nevertheless, in unclear situations, consultation between supervisors is the first step towards the judgement. For example, it is often complicated to assess the level of corrosion or to what extent the data from the vehicle registration certificate corresponds to the results of visual inspection, and that process includes seeking help from colleagues. Two supervisors expressed this as follows:

“Here’s the deal, if it were, so to say, up to us to make the decision, I can then see that we are... Some people think in one way, other people in another... To some people one millimetre doesn’t make a difference, they say that there has to be some tolerance, while others say that there shouldn’t be any tolerance ... We don’t always agree with a certain assessment.”

“Take, for example, colour. One colleague will say that the car is grey, and another will say it’s blue. I had a Seat Anthea, it said it was blue, but to me it was grey and I sold it, for me it was grey. But the vehicle registration certificate said it was blue. And some people said it was grey, while others said it was blue. You know, that’s because of those things, through corrosion. Corrosion is what is most often questionable, you have to check it additionally, maybe by touching it so to say, and you take a screwdriver to try whether it really affected the structure of the material or it’s only on the surface and so on.”

On the other hand, unclear situations may be caused by confusing data from the device. In other words, data from the device does not correspond to the subjective assessment. This is where supervisors most often pointed out the need to view the subjective assessment as a means to reassess data from the device. So it’s not only about checking the subjective assessment, in circumstances which allow for it, through available measurements and results from the device, but also vice versa, a continuous subjective involvement in the inspection process has the role to confirm or refute data from the device which should, at first sight, be objective and reliable. For example, one of the supervisors expressed this as follows:

“Those lift racks ... the runways on the lift racks are quite ... One time, my colleagues and I, we don’t do that often, but if we suspect something regarding suspension, we put it over the pit to see. Lift racks are relatively new, but we got accustomed to the pit, let’s say, over the years. It’s good, those lift racks are good, but sometimes, sometimes it’s not clear whether the tie rod end is loose or not. So then we go over the pit and we move the steering wheel by hand. Look, technical inspection is a serious thing. We have to be sure.”

In any case, participants most often gave an example of a tester for shock absorbers and a device to conduct an eco-test, and in some cases, a roller brake tester. The tester for shock absorbers has been mentioned multiple times as a relatively unreliable device that causes confusing situations:

“The tester for shock absorbers is not a particularly reliable device... That device is not mandatory required at stations by the rulebook... The rulebook says that if

the shock absorber is not oily, if it's not ... If it's well fixed, if it's subjectively good, then we let it pass ... We don't always trust that device because we've seen many times, for example, that a new vehicle comes from Skoda, not one, but a number of such cars which have 15-20 kilometers, and the device says that the shock absorber is not good while the car is brand new ... It's not a coincidence, it happened in the case of approximately 50 vehicles ... Considering that the use of that device is not mandatory in the station, we can ignore it".

On the other hand, it is not possible to conduct an eco-test without using the device, but confusing situations have often been mentioned. Sometimes it happened that data on the number of revolutions or gas emission did not match with the colour of smoke seen by the supervisors or with the smell they sensed at that moment. It is always a question of data which supervisors consider to be unrealistic. Then, based on the subjective doubts, they repeat the checks until they get the results for reliable estimation: whether it is a case of an inadmissible irregularity. Sometimes, they combine the data from the device with their subjective perception in order to decide whether to let the vehicle proceed to the next phase of the inspection. In general, the whole process was described by the supervisors as self-evident and an integral part of their work, as well as another aspect of a human factor and technology at work being intertwined, which only seemingly doesn't leave a lot of room for uncertainty.

### **SUBJECTIVITY AND DEVICES: DIFFICULTY OF WORK**

In general, supervisors did not interpret the technical, i.e. non-relational [10] part of their job as difficult in the usual terms which are considered to be parameters for the difficulty of work. They do not think that the working hours are problematic, physical and mental efforts during vehicle inspection are not indicated as particularly problematic, the time needed to inspect a certain vehicle has been estimated to approximately half an hour, the number of vehicles inspected during each shift is only occasionally too big, and busyness, although foreseeable only to a certain point, is more linked to the car market cycles, city lifestyle or clients' annual leaves. The same can be said for the role of the turnover in the operation of the vehicle testing stations – although the supervisors' salaries are in correlation with the generated revenue of the station and may vary on a monthly basis, supervisors did not interpret that as an important aspect which would affect the difficulty of their work. Finally, the elements of functional flexibility that are most often manifested through work rotations and performing various tasks – from the beginning of the technical inspection until approval and technical documentation – have not been mentioned as problematic as long as work task integrity is preserved.

Essentially, the difficulty of non-relational part of their work is most often linked to the sense of professionalism and manifested through the perception of a good quality inspection. Sense of responsibility is indicated through understanding that subjective aspects of the inspection should be approached with concentration and awareness that the decisions made in that way cannot be attributed to the neutrality of the device, that they affect the inspection results and that the supervisors are the only ones responsible for such decisions. As one inspector claimed:

“So, in my opinion, that is the most difficult part of our work since we influence the results. It is up to us to assess whether the vehicle as such is roadworthy or not. Without us, without our word, without our signature, etc., I don't think that our work would mean a lot. If we only had devices, if everything was done using devices, we wouldn't have a lot to do, so to say. We connect a device, the device says roadworthy or not, and we have nothing to do. But, I think that we contribute greatly to the technical roadworthiness because... I suppose that not every system, every set can have a device for it. And we contribute a lot, let's say, to the technical inspection.”

Also, the majority of other interview participants singled out subjective assessments as the hardest part of a non-relational, i.e. technical work. This is most often expressed by using the term “what we have to assess”, whether it is a question of replacing the brake discs because they are worn out, a question of the level of corrosion, its position on the car, for example on pressure lines or on brake hoses, whether the corrosion is only on the surface or a structural one, or a question of the condition of the undercarriage. Clients sometimes quite vaguely suggest that there is something wrong with some parts of the vehicle, which was compared, by one of the many supervisors who mentioned the difficulty of the undercarriage inspection, to the visit to the doctor to whom you say that “something hurts” without specifying what exactly and where it hurts. Similarly, a client says something along the lines of “I hear some noise in the front left side”, which means that a supervisor must carefully inspect a number of things, from the ball and the tie rod end to the shock absorber, without clear chances that he would indeed find the source of the problem. The situation is sensitive because it could mean that even after consultation with colleagues they didn’t find anything wrong with the car and that they must let it pass despite warnings by the owner of the vehicle. Overall, subjective assessment is not only the sole basis for making a decision during certain phases of vehicle inspection, but it is often also the hardest part of the work: “The most sensitive part would be the decision-making process where we are responsible for it and where, so to say, there has to be a subjective impression”.

Therefore, it is not surprising that devices are seen as something that facilitates and speeds up work, regardless of the confusing situations. The devices to conduct an eco-test and to check the brakes and the lights were the ones most often mentioned. However, other phases of inspection have been mentioned as well, in which the importance of subjective assessment was emphasized, such as checking the shock absorbers. Essentially, participants without exception consider that the existing technology and the introduction of digitalisation are positive and represent an active assistance which does not undermine nor remove the elements of a human factor, i.e., their contextual knowledge and subjective insights which they consider to continue to be an integral part of their work. The only difficulties were mentioned in relation to the initial stages in the process of digitalisation (e.g. introduction of RFID cards) which were observed in terms of time necessary to make the technology work (“until it works”) and as an integral part of inspectors’ own adjustment to a slightly different way of doing things.

There are several baselines confirming that technology and devices facilitate work. First of all, it has been mentioned multiple times that devices, analogue and digital ones, speed up the overall inspection. Secondly, during the different inspection phases, work process has been simplified in terms of drawing conclusions on the roadworthiness and non-roadworthiness. Thirdly, although data from the earlier analogue devices allowed for some derogations, the increased precision of data from digital devices is considered a good thing since it indicates the accuracy without the rest. This is adequately summarized in the following statements:

“That OBD is quite helpful. For me, it’s much simpler. OBD is a connector that connects to the vehicle and shows the number of revolutions and temperature. It can do some other things as well, but to us it’s important that it shows what we got through the clamp on the battery and the probe for oil temperature measurement in the engine. Now we get that information through that connector. It simply speeds up the process, on and off.”

“The difference is, well, big. We cannot read from the analogue devices, so to say, a hundred percent, each decimal of the braking force. While the digital ones are much, much more precise, much more accurate so to say, and we write down what we see. The pointers on analogue devices don’t show the tiny, fine lines, you know, the lines which would indicate exactly the correct one. So it’s not as

precise and the digitalisation and all of it is, in my opinion, much better and much more accurate, so to say.”

*This difference in accuracy – how crucial is it for the assessment?*

“Well, it’s not crucial, it’s not possible that there is such a big difference. Previously we worked with analogue devices and there was more rounding off, let’s say. Let’s say that we have 2 500 kilo-newton shown on the digital one, or 2 540, then we cannot read this 40, 44 on the analogue one, we always round it off to the whole number. The difference may vary only for a few percent, but, as I said, the digital one is simply more accurate.”

Finally, it was revealed that participants consider technology and devices as something that also facilitates relational aspect of work [10], especially in terms of ruling out clients’ suspicions regarding the outcome of the inspection. It is indicated that it is simply easier to give the news to the clients about the negative outcome of the inspection when it is substantiated by “hard” data, especially when it comes to the results that were read digitally and there are no doubts regarding human or subjective errors.

## **INTERACTIONAL PATTERNS**

According to the findings, we identified two basic interactional patterns in the work of supervisors. The first one refers to the communication among themselves during working hours, and the second one to the communication with clients. Considering that each supervisor completely inspects the vehicle independently and gathers, writes down and assesses testing results on his own and does not forward or explain them to someone else for the purposes of further analysis, it was shown that the interaction with colleagues at work was occasional and mainly functional. It happens mainly in situations when there is a need to seek or give advice regarding a problem during the inspection, or when the business is slow and it is possible to talk about work or something else. The supervisors share the space where they work, they are close to each other at every moment, and yet the optional conversation is sporadic and concerns some casual comment when passing by or happens when the business is slow. Therefore a big importance is attached to the conversations which solve the problems, i.e. when an assistance is sought to determine the roadworthiness of a certain part during the inspection.

On the other hand, the supervisors consider that the communication with clients is the biggest problem not only in a relational part of the work, but also altogether. To that extent, immediate social context shapes the actors, the character and the content of the communication in a specific manner. The actors are technicians and clients who are mainly not technicians. In terms of communication character, both technicians and clients recognize and internalize their roles when it comes to decision-making powers and outcomes of those decisions. The communication is normally one on one. Communication relates to vehicle (non-)roadworthiness, briefing of clients on the state of the vehicle, propositions and suggestions in case of repairs, preparations for the next technical inspection, etc.

Supervisors point out that this is an extremely stressful situation which is not shaped only by them, but also by clients – a situation manifested through the process which involves two sides. A minor part of supervisors indicated that clients and interaction with them should be completely eliminated, while one supervisor stated that he even considered engaging security guards:

“But in my opinion I shouldn’t have anything to do with clients. Because I’m not here to talk endlessly about what isn’t roadworthy and so on. It would be good to have a policeman or a guard since that would solve the problem when a churl comes and starts swearing, especially when more complicated problems need to be dealt with”.

Nevertheless, most of them indicated that they do not have problems with all clients, but mostly only with those who do not want to accept a negative outcome of a technical inspection. For instance:

“Most often it happens when a vehicle doesn’t pass the technical inspection. Most often. And some people are simply angry, some probably don’t understand what exactly is a technical inspection and why they have to fix something. So ... people are different, we are not all the same. Some simply overreact, some won’t calm down, and some really insist on passing the technical inspection. We have to explain to them, or at least try, try to explain that that’s simply the case, that the car is... some things need to be fixed because they are not safe for the road. So in that respect there is a lot of arguing with people and discussions why, how, why you can’t, why you won’t let me pass. Sometimes there is some yelling and everything.”

Such situation is problematic because the supervisors have to insist on their assessments of roadworthiness based on the inspection, despite the fact that clients are pressuring them (by arguing, etc.) to change their assessment. Nevertheless, some supervisors stated that communication implies two sides, i.e. that they themselves have to work on improving their communication with clients.

“Some colleagues should definitely work on communication. You can’t just come to the car and say LIIGHTS. No, first you have to say hello. And that’s what I already mentioned, that is, some people are not entirely comfortable with going to the vehicle testing station. Because he doesn’t know, especially, if he has, I don’t know, Skoda Fabia let’s say, he doesn’t know if that car is, I mean... You know what, everybody is afraid, they are all afraid of getting the note to go to the mechanic, you know. And then that gives them a headache. Why? Because social circumstances in Croatia are the way they are. And then you just come and don’t know how to talk to people. But then again, that’s not ... That’s a question of how they were raised at home. I don’t know, I guess I was raised better than that. I guess, I don’t know. It’s not difficult to smile to people”.

Overall, participants interpret the interaction with clients as the hardest part of their work. Not only it is stressful, but the supervisors see it as an extremely important element in assessing vehicle roadworthiness because clients need to get, for their own road safety, quality information about the urgency of certain repairs or less significant problems that need to be resolved before the next inspection. Finally, some participants interpreted interaction with clients through the perception of the performed good quality work, where the outcome of the inspection is irrelevant, and a client advised by an expert is put in the foreground.

## **DISCUSSION AND CONCLUSIONS**

Two main topics of the present study aimed to descriptively determine potentially patterned elements of subjectivity-technology issues in specific organizational context of PTI inspectors’ work in two PTI stations and to relate our findings to referent theoretical concepts mentioned in the analytic frame.

Descriptively based themes which emerged through the procedure of summing up the findings suggest strong and enduring intertwining of human factor and technology in this specific context. Subjective judgements were estimated as crucial, single and irreplaceable point of reference only in one segment of “assessing vehicles’ roadworthiness” theme, although even there technology is not interpreted as generally unwanted but mostly as currently unavailable. Also, subjective judgements are strongly mediated by the use of

senses. Otherwise, subjective judgements are regarded as a necessary human activity permanently related to simultaneous use of devices in the process of inspection, where recognizing complex task related appearances and spotting unusual and unexpected events is integral part of the work. Our participants indicated that subjectivity is always present, even when devices are interpreted as the sole or crucial basis for evaluation. On the other hand, technology is also present all the time: even where devices for inspection are not available, the subject of inspection, the vehicle itself represents some kind of knowledge-derived tool or device that has to be tested and checked. However, in terms of working equipment, technology is interpreted as a constitutive and integral element in everyday working activities and related to devices needed for inspection to be done even when they display confusing or suspicious data. In that sense, participants considered digitalisation as proper and welcomed part of technological advancement which allows for more precise estimates, and which does not exclude but corresponds to their subjectively based judgements and decisions.

Generally, when it comes to issues of work autonomy, discretion, skills and work experience, we found no strict division in the meanings attributed to subjectivity and technology. In that part, it corresponds to Liker, Haddad and Karlin's notions of the contingent nature of work-technology relationship at an organizational level [3]. In the present study, organizational contingencies refer to significant autonomy and discretion in inspectors' work in which subjectivity and technology are interrelated and complementing rather than mutually exclusive. If there is no device available, evaluation is subjectively made and it can be interpreted as valid and objective. In other cases, if subjective indication is persuasive, it is checked by devices anyway. If devices offer suspicious data, these are additionally sensory checked or considered in dialogue with coworkers. If the subjectivity is the toughest part of the work, devices and technological advancement can make it easier and faster. However, inspectors are always the main actors when it comes to making decisions on the vehicle's or its segment validity. It has been most clearly visible in "is it valid or not" expression which participants frequently repeated, pointing out that it is up to them to make a clear, final and responsible estimate.

In sum, these findings represent the main patterns of subjectivity-technology aspects in specific organizational context we could outline. These findings can be related mostly to findings in a number of research Barley and associates conducted in different settings [9-12]. For example, in the study of CT scanner technicians' work it was found that technological advancement does not necessarily threaten their work, but, at least partly, rather broaden the scope of interpretation of data and making decisions. Correspondingly, in the present study, our participants described digitalisation of some devices as welcoming advancement in work which is already marked by autonomy and discretion in the process of careful data interpretation and objective and responsible decision making. Furthermore, the meaning of professionalism that our participants expressed mostly in terms of responsible evaluations which stem from their mechanical experience and knowledge and abilities to transform technologically and subjectively derived representations of vehicles' conditions allows us to put in the forefront Barley's notions of transforming the mainstream meaning of professionalism toward possibilities for more horizontally organizational structuring. As it turned out, our participants did not complain to existing organizational structure and did not relate that issue with their sense of professionalism, maybe mostly because the character of their work left a room for autonomous use of devices, relatively independent estimation and decision making on vehicle's condition. In that part, there were no hierarchically superior professionals to interpret the data they collected or to check their interpretations on the grounds of inspectors' unprofessional workplace status. Even in unclear and rare troubling situations with regard to data and estimates they referred to their immediate coworkers – also technicians.

At first glance, most of the meanings which inspectors attributed to subjectivity-technology aspects of their work can be qualified in Barley's terms of non-relational core of technicians' work [10]. They do really manage the empirical interface, i.e., bridge the material world (vehicles and devices) and a world of representations (data and test results) in the process of interpretation and decision making. However, Barley's "relational logic" of technicians' work in the present study seems to be manifested and interpreted by supervisors in a slightly different way. In the local division of labour they were not primarily oriented to superior positions of professionals who would use the data stemming from technicians' work nor were they "primarily responsible for creating or maintaining the technical infrastructure that enabled other people to do their work" [10; p.422]. Although we found Barley's differentiation of non-relational and relational aspects of work inspiring and useful and we realized it was created in an attempt to build the ideally-typed (and historically contingent) model of technicians' work, we also found that these two aspects cannot be strictly separated in daily work routines, but are constantly integrated in the process of presenting the results of inspection to clients. This interaction is hierarchically structured with supervisors having authority over the final outcomes of the inspection no matter what the client's expectations or opinions on the vehicle's condition are. Since in many cases presented outcomes do not match the expectations of, and often are even challenged by clients, this interaction was interpreted as the most difficult part of work which includes not only disagreements, but also refusals, often followed by verbal aggression and insult. It is mostly one-on-one type of communication, with PTI station manager involved very rarely, mainly in the most troubling and incident situations. PTI inspectors' authority and power to decide whether a vehicle is in condition to be licenced for participation in traffic is "non-relationally" based on professionally conducted testing procedures involving all subjective and technological sequences and "safety first" principle in mind, but, on the other hand, it is "relationally" openly, and mostly unsuccessfully undermined by clients who in this interaction occupy a subordinate position.

In local organizational division of labour, these autonomy, discretion and authority do reflect possibilities for rethinking the meaning of professionalism along more horizontal ways of organizational structuring, but in the case of supervisors in vehicle inspection stations it includes some kind of unintended consequences related to the strong feeling of work-stress and anxiety in their interactions with clients as the key actors involved in work interactions. These interactional configurations are somewhat corresponding to patterns of occupational identity Darr and Scarletta described in the case of computer technicians [13] with the important difference contained in the fact that computer technicians in their study were working primarily in the sector of services while the job of PTI inspectors in PTI stations falls under the public authority and activity of general public welfare. It means that interactions with clients in the present study were not limited to the matter of technical support and eventual usage-supervising, but were rather characterized by communicating outcomes that are binding for clients. In that sense, communications *are* perceived as the integral part of the job, often as the most difficult, stressful and therefore sometimes mere unavoidable element, but simultaneously indispensable condition [14] for work to be done correctly.

Generally, the present study's findings coincide with notions on theoretical importance of great varieties with regard to technicians' identity and organizational contingencies which do not allow for excessive and hasty generalizations. As Darr and Scarselletta simply put: "... not all technicians are alike" [13; p.71]. We tried to contribute to their indication that interaction with technology represents an important component of technicians' work, particularly in occupations where subjective assessments play a more significant role than it is usually taken into account. When these findings are complemented with highly contingent character of

“relational” part of technicians’ work, it is possible to provide an empirical basis for more dynamic approaches to the research of technical work. On the other side, limitations of the present study are related to sample size and inability to conduct extended field and ethnographic work. Since we do consider extended fieldwork participation as constitutive for qualitative research, a warning in this regard has to be clearly issued. However, we conducted other activities which allowed us to triangulate interview data with extended conversations with second author and her suggestions during repeated field visits. Therefore, our findings enabled us to descriptively analyse one among many highly contingent and socially specific contexts of technicians’ work which can help in future people-technology-organization studies.

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# RENAISSANCE OF HERBERT MARCUSE: A STUDY ON PRESENT INTEREST IN MARCUSE'S INTERDISCIPLINARY CRITICAL THEORY\*

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## ABSTRACT

Recent years have witnessed a revival of interest in Marcuse's critical theory. This can be partly ascribed to Marcuse's interdisciplinary approach to humanities and social sciences. Many of Marcuse's ideas and concepts are tacitly present in contemporary social and ecological movements. Contemporary literature on Marcuse is positively inclined to his theory while the critique of Marcuse dates back to the '70s, and remains largely unimpaired. This fact poses significant challenges to the revival of Marcuse's critical theory. This study sets out to report on current interest in Marcuse's critical theory trying to correct "past injustices" by responding to negative criticism. The main flaw of such criticism – as we see it – is in failing to perceive interdisciplinary character of Marcuse's critical theory. Marcuse's renaissance cannot be complete without, to use dialectical term, subsuming the history of negative criticism.

## KEY WORDS

Marcuse, interdisciplinary critical theory, Frankfurt School, social movements, critique

## CLASSIFICATION

JEL: B24

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## INTRODUCTION

Horkheimer, Adorno and Marcuse were among prominent representatives of the Institute for Social Research (commonly known as the Frankfurt School). They pioneered interdisciplinary approach to humanities and social sciences. Their distinctive project (the critical theory) draws arguments and empirical data from various disciplines such as philosophy, economy, sociology, psychology, literature and arts. Hence, the interdisciplinary character of the critical theory. The critical theory became a platform to various social movements that demanded radical social and economic change. It goes without saying that the trio enjoyed a celebrity status (although Adorno became the target of students' attacks and negative criticism). Until recently there was a significant discrepancy in contemporary reception of Marcuse's and Adorno's ideas. As Zill observes in the newspaper article: "Everyone talks about Adorno (...) Teddy has won the day ..." [1]. However, recent years have witnessed the renewal of interest in Marcuse's critical theory. This study aims at exploring Marcuse's renaissance. Contemporary literature on Marcuse is positively inclined to his theory, while the critique from the '70s remains largely unimpaired. Still today a systematic response to negative criticism is missing. Hence, in this article I respond to the main critical arguments and thus attempt to extricate some of Marcuse's most progressive ideas from misinterpretations. This misconception is largely caused by critics' unfamiliarity with the complete body of Marcuse's works characterized by an interdisciplinary approach to the critical theory. Introducing psychoanalysis into Marxism (to give one example of Marcuse's interdisciplinary approach) is not, as critics would have it, a deviation from Marxist theory but rather a response to the crisis of Marxism. Marcuse's renaissance cannot be complete if the history of (flawed) criticism is about to repeat itself.

A distinctive trait of Marcuse's oeuvre is the continuity of thought and philosophical imagination for the purpose of liberation of individual(s) and for the creation of a more humane world. Hence Marcuse's later works are nothing more than an elaboration of ideas already presents in his early writings. An individual in his concrete historical existence has taken a central place in Marcuse's theory right from the beginning. Marcuse's critical theory of society is oriented towards overcoming of capitalism and its outputs. Thus, critical theory has an open dialectical structure. The sublation of capitalism is carried on by the *praxis* defined as the self-negation of the principle of historical materialism. Marcuse's thought is dialectical. He attempts to pinpoint and demonstrate negative and destructive elements that are detrimental to human being and at the same time to indicate the *praxis* of sublation: negation of the established reality. This negation should be understood in terms of the "radical act" *praxis*. Marcuse's critical theory and radical *praxis* formulates a politics of refusing that which negates human being. Critical theory as a theoretical position and revolutionary-directed thought continues on Marcuse's previously conceptualized "concrete philosophy". In the concrete philosophy Marcuse attempted to attain theory of historicity for the purpose of grasping the concrete historical situation. On the ontological level Marcuse attains the concept of historicity, as the origin and foundation of being(s), through interdisciplinary synthesis of Hegel's, Marx's and Heidegger's thought. Marcuse, thus, conceives labor as the source of historical sustainability of everything that exists. Thus, labor is the permanent process of cultivation, appropriation and abolishment. The discrepancy of the given world and human being induces process of mediation. For Marcuse this concept of historicity can be identified with Hegel's ontology which introduces the process of mediation and motility of being. Marcuse's interdisciplinary approach is evident as early as in his complementing of the ontology of labor with Heidegger's thoughts from *Being and Time*<sup>1</sup>. Heidegger's temporality, because it is authentic, constitutes necessary supplement to the

historical materialism. Heidegger's temporality cannot reconcile itself with the inauthentic social situation. Hence, Heidegger's temporality points at the same direction as Marx's vision of history. However, Heidegger's temporality must be situated into the concrete material production of life and historicity, but in doing so the authenticity of *Dasein* functions as the regulative principle. On the question *how concretely is authentic existence possible?* Marcuse seeks the answer in the analysis of a basic situation in which there is an awareness about possibility of radical act directed toward realization of true, authentic, human existence. The human historical situation is in the foreground but the transcendental-ontological level of Heidegger's temporality is consciously used as a corrective to bad practice.

An insight into the autonomy of technological development poses a problem to Marcuse's concept of historicity. Marcuse perceived that the new subject of historical faring is technology and technological development which subdues human being by technological rationality. It cannot fit into Marcuse's decisive understanding of historicity, in which self-realization is possible only through labor<sup>2</sup>. The criteria of happiness which directs revolutionary *praxis*<sup>3</sup> becomes incompatible with the technological development. Hence, Marcuse's insistence on the tension between essence and appearance becomes obsolete: technological reality is in itself realization of reason. This, however, deprives philosophy of its second dimension. Nonetheless, Marcuse does not completely abandon the notion of labor and concept of historicity or for that matter any previously attained ideas and positions. He uses historicity to differentiate between different historical epochs in relation to labor<sup>4</sup>. Yet, it should be pointed out, however, that Marcuse circumvents re-thinking of the concept of historicity and, rather orients himself to the critique of the developed industrial society. Marcuse's critique, and concrete guidance for the revolutionary change, is directed: 1) at the existing order of things under the "performance principle"; 2) interdisciplinary supplementation of Marx's theory on revolutionary subjects and 3) to the critique of the values of mass society. Nevertheless, Marcuse attempts to regain philosophy's second dimension. This is evident in his decisive stance about qualitative differentiation between mass society and the society of aesthetic ethos<sup>5</sup>. This is only possible by a radical change in relation to nature. Such a change can be expressed by the term "pacification of existence".

In the end, as Kellner [2] notes, Marcuse's work started as a reaction to the crisis of Marxism (bureaucratization of Soviet state and integration of working classes into capitalism<sup>6</sup>) and Marcuse's response consisted in the attempt of restoring Marx's dialectic and focusing on the subjective factors as the basis of radical social change. Farr writes: "Indeed, Marcuse's entire project can be viewed as a quest for a new subjectivity" [3; p.8]. It is in this context that Marcuse's investigation into Freud's theory should be understood<sup>7</sup>.

Hence, Marcuse's complete oeuvre is defined by the consistency of dialectical thinking (through negation, preservation and elevation), refuting of any positivism favorable to reality, by the care for an individual and by the overcoming of reified relations and creation of a more humane world in which human being (re)discovers oneself and sees the world as one's own doing, as a stage in which one, in a peaceful and libidinal coexistence with others, can develop one's all-around being. This qualitatively different world would be imbued with happiness as a universal and not subjective condition and labor would become free and creative activity of liberated individuals. The possibility of the new world is not mere utopian vision, because the contours of the new are already present in the existing. Especially interesting for contemporaneity is Marcuse's later thought, where he opposes enclosing of multidimensionality by insisting on negative thinking. The remaining one-dimension is a consequence of the labor that is no longer burdensome, of the abundant society that is able to produce goods for massive consumption and of the technological breakthrough. The abundant society created the image of security, happiness and abundance. But in this state in which

rationality has the character of technological rationality all alternative modes of organization and life are absorbed. Marcuse could not reconcile with this state as the permanent one. He remained dedicated to the traditional notion of *logos* and insisted on the reality of reason. This led Marcuse on the interdisciplinary quest for liberation and hence to search for a liberating potential in the character of labor, technology, instinctual structure and dynamics, art and aesthetics and to critical reassessment of democratic principles such as tolerance. However, the liberation for Marcuse presupposes the *praxis* expressed through the “radical act” and, later, the “great refusal”. Marcuse directs *praxis* towards creation of the “new sensibility” and the “new rationality” that would oppose any aggression towards humans, nature and other living beings<sup>8</sup>. An alternative dimension opens by cooperation of art and technology towards creation of the society as the work of art.

Marcuse remained dedicated to finding paths to concrete liberation. As Kellner notes: “The quest for the concrete would eventually lead him towards inquiry into the nature of labour, needs, sexuality, consciousness, art and especially into the nature and dynamics of contemporary social organization” [2; p.64]. Hence, Marcuse’s interdisciplinary search for ranges from the analysis of authentic art<sup>9</sup>, the concept of tolerance<sup>10</sup>, the tension between essence and appearance, and technology. However, even though these topics could be addressed as separate subjects, they should be understood and treated in a much broader, interdisciplinary context that characterizes Marcuse’s philosophy. There are several reasons for this. First and foremost is to avoid the trap of de-contextualization and abstraction to which negative criticism fell when it treated Marcuse’s ideas without reference to his early essays<sup>11</sup>. Second reason is to extricate Marcuse’s ideas from almost half a century old misconceptions. Third reason is to offer meticulous reconstruction of how those ideas had been developed<sup>12</sup> and to show persistence in Marcuse’s thought.

## CONTEMPORARY MARCUSE

As an introductory sentence on Marcuse’s works from the contemporary perspective and in the light of contemporary social movements and struggles, a line from the movie *Shortbus* will serve: “just like the sixties only with less hope” [7; p.161]. Reflecting on Marcuse’s works from today’s perspective, Thompson writes: “Many of the ideas that Marcuse put forward as cautionary tales in *One-Dimensional Man* had become the profane features of everyday life by the time Jameson published his groundbreaking book on postmodernism [*Postmodernism*]. Indeed, it is impossible to read many of Marcuse’s observations without being struck by the feeling that they are prescient first drafts, thematic sketches destined to find their way to center stage a generation later” [7; p.163].

During global justice movements in 2005 Kellner reminded (one more time) on the continued importance of Marcuse for understanding the strategy and sociopolitical horizons of contemporary struggle: “Yet I would argue that in the present conjuncture of global economic crisis, terrorism and a resurgence of U.S. militarism, and growing global movements against corporate capitalism and war, Marcuse’s political and activist version of critical theory is highly relevant to the challenges of the contemporary moment. Marcuse is especially useful for developing global perspectives on domination and resistance, radically criticizing the existing system of domination, valorizing movements of resistance, and projecting radical alternatives to the current organization of society and mode of life” [8; p.3].

In recent years, we have witnessed radical movements that stand up against what denies „us“, and as such they reflect a renewed interest in Marcuse’s philosophy<sup>13</sup>. Marcuse’s thought proves to be of a crucial significance to the renewal of contemporary radical praxis and politics of (great) refusal: “Acts of refusal can be observed in groups of workers going on

strike to oppose austerity measures, resisting a demanded speed-up in productivity aimed at restoring the rate of profit, or refusing to accept cuts in order to 'pay off the deficit' from massive state intervention to rescue capitalist enterprises, which are themselves the victims of a crisis of profitability, of capital's valorization. Other examples include the 2010 United Kingdom's mass student protests refusing the burden of debt from education, which is becoming an unaffordable privilege even as it is being restructured into an instrumental production line for the social factory; the 2011-2012 spread of protest occupations across the Americas, Europe, and elsewhere, which for all their inchoate uncertainty were authentic expressions of protest and resistance; and the 2016 Nuit Debout mobilizations against, among other things, neoliberal labor law reforms in France. Indeed, the feeling-in-the-dark nature of such spontaneous movements may be seen as a mark of their authenticity. As with earlier resistant antagonistic subjectivities in Marcuse's time (e.g., in France in May 1968; in Italy in the 'Hot Autumn' of the following year, no less than the movement of *autonomia operaismo*, which reached its high point in 1977; and in the United States, the anti-Vietnam War protests and campus protests of the 1960s and 1970s), it is possible to see the attempt at becoming, at self-creation in and against the objective world of capital and instrumental reason" [9; p.59].

Reitz who aims to develop a theory of revolutionary ecological liberation by drawing on Marcuse's thoughts on ecology points out: "Since the 1970s, the time of Marcuse's initial prominence, the world has become ever more aware and rightfully disturbed about multiple forms of environmental disaster on the horizon. These include extreme weather events such as hurricanes, floods, droughts, and wild fires, chiefly in terms of global warming due to the burning of fossil fuels, and also resource waste, mismanaged plastic waste streaming into the oceans, soil contamination, degraded water and air quality, depleted ozone, ocean acidification, habitat and biodiversity loss. Each of these is also profoundly enmeshed within a world-wide system of economic inequality and conflict. Marcuse's work has the strategic radicalism and optimism that are needed more than ever today" [6; p.2].

Feenberg (correctly) stresses that in the contemporary social criticism Marcuse's key ideas are unduly unacknowledged<sup>14</sup>: "His relevance is proven by the fact that his key ideas appear unacknowledged in the writings of many contemporary social critics" [10; p.229].

Is there some special insight into democracy as such that could be linked to Marcuse's theory<sup>15</sup> in connection to the Paris street movements of the 1968? It was an insight about democracy as an excess. "Excess" usually means an unexpected and unwanted event that most often ends in violence. However, the word excess has another meaning as well: excess as the surplus that surpasses the norm or standard. Hence, it is possible to live a life without this surplus. On the other hand, the enjoyment of surplus makes qualitative difference in the enjoyment of life. In the same way democracy appears as an excess that (always) carries those who do not fit into the establishment, those who are repressed (slaves, proletariat, minorities, migrants, etc.)<sup>16</sup>. Democracy would be useless, as Rancière asserts, without this excess. In conclusion of the *Hatred of Democracy* Rancière writes: "It is because democratic man is a being of excesses, an insatiable devourer of commodities, human rights and televisual spectacles, that the capitalist law of profit rules the planet (...) Not only are the vices of the system the vices of the individuals whose lives it governs. But the people most guilty, the exemplary representatives of this vice, are those who want to change the system, those who spread the illusion that it can be transformed so they can further indulge in their vices (...) With politics forgotten, the word democracy thereby becomes both a euphemism designating a system that one no longer wants to call by its name, and the name of the diabolical subject that appears in place of that effaced word: a composite subject where the individual subjected to this system of domination and the one that denounces it are amalgamated. To paint a robotic portrait of democratic man, the best thing to do is to combine

these characteristics: the young, idiotic consumer of popcorn, reality TV, safe sex, social security, the right to difference, and anticapitalist or ‘alterglobalist’ illusions” [12; pp.88-89]. One could easily note the silent presence of Marcuse’s ideas.

Contrary to Rancière, Marcuse assumed that the true, human content (or for that matter democratic content), could be attained only through abolition of surplus (excess). In accordance with that assumption Marcuse in *Eros and Civilization* made the distinction between repression as biologically conditioned and surplus repression as socially conditioned. The act of “great refusal” could be then interpreted as an act against this democratic excess that continually carries some form of inequality and repression<sup>17</sup>. Furthermore, Rancière description (and criticism) of the democratic man is similar to Marcuse’s one-dimensional man: “We are again confronted with one of the most vexing aspects of advanced industrial civilization: the rational character of its irrationality. Its productivity and efficiency, its capacity to increase and spread comforts, to turn waste into need, and destruction into construction (...) The people recognize themselves in their commodities; they find their soul in their automobile, hi-fi set, split-level home, kitchen equipment. The very mechanism which ties the individual to his society has changed and social control is anchored in the new needs which it has produced” [13; p.11]. Rancière criticized the vices of democratic man but so did Marcuse who argued that the un-freedom is not in satisfaction but already in the need and want. However, while Rancière posits “composite subjectivity”, the one who at the same time in an amalgamated way reconciles the acceptance and denouncement, Marcuse posits “rebellious subjectivity” who on instinctual level opposes (and refuses) any surplus repression (excess). As Garland notes: “Resistant subjectivity can be seen in the negation of identity-thinking and the spurious naturalization of fixed social roles, such as gender divisions and the reduction of sexuality to genital sex-as-procreation. Put another way, there is sexual desire, or the erotic – Marcuse’s pleasure principle – a uniquely rich process of life lived for its own sake, as an end in itself, which does not fulfill any functional instrumentality; thus, this desire can be viewed as a significant and inherently subversive activity, making noticeable the system’s cracks” [9; p.67]. Building on Marcuse’s understanding of subjectivity, Katsiaficas<sup>18</sup> [14] aims to develop a theory of the “eros effect”<sup>19</sup>. Marcuse’s “great refusal” as negation of identity thinking and radical practice could be explained in Holloway’s terms of power-over and anti-power: “Anti-power, (...) is not counter-power, but something much more radical: it is the dissolution of power-over, the emancipation of power-to (...) Anti-power is fundamentally opposed to power-over not only in the sense of being a radically different project but also in the fact that it exists in constant conflict with power-over (...) To find anti-power, we do not need to look outside the movement of domination: anti-power, anti-fetishisation is present against-in-and-beyond the movement of domination itself, not as economic forces or objective contradictions or future, but as now, as us” [15; pp.24-60]. Thus, “anti-power” as radical practice challenges and questions in the same vein as the “great refusal” repressive “power over” human beings.

Marcuse’s theoretical framework could be observed as latently existing in. These movements share some striking characteristics with the New Left although capitalism underwent radical transformations since Marcuse’s time<sup>20</sup>. According to Funke, Lamas and Wolfson [16], these characteristics include: “an embrace of a diversity of actors and fronts of struggles, a commitment to leaderless and prefigurative forms of organizing, and a participatory governance process based in grassroots democracy and consensus decision making. Moreover, much of today’s activism displays a distrust of existing institutions, a critique of elite financial power, the physical and virtual occupation of space, and a strategy of change, grounded in voluntarism and spontaneous uprisings rather than resilient movement building. Analysis of the wave of protest of the 1960s and 1970s, reveals critical similarities to today’s

movement politics, along the lines just mentioned, and thus calls for a revisiting of Marcuse's engaged critical theory, in order to carefully tease out insights from the struggles he witnessed, participated in, and reflected on. Moreover, this excavation of Marcuse's frameworks may help scholars and activists identify the strengths and shortcomings of contemporary theory and practice of resistance" [16; p.4].

Moreover, traces of "great refusal" and "post-technological rationality" could be observed in practice, as Vieta [20] points out, in the alternative community economies, radical education initiatives and recuperated spaces of production. All those "excess" strata of democracy such as: precariously employed, chronically unemployed, those unemployable, those whose services and skills are no longer required, marginalized and indigenous groups, etc. practice "great refusal" by reorganizing their life and economy on the very margins. As Vieta notes: "In their praxis, such experiments immanently critique capitalism's 'sacrosanct' pillars of private property, profit, self-interest, and competition by replacing them with common ownership, mutual aid, and cooperation" [20; p.271]. Alternative educational institutions could be explained as Marcuse's "areas of withdrawal" from the established reality. Finally, the "great refusal" could be observed in workers management that is taking place in Latin America's workers recuperated enterprises. Even though alternatively organized communities, educational institutions and workers movement may lack fully formulated (political) programs or projects for the total transformation of society that Marcuse envisions, they nevertheless provide the evidence that Marcuse's completion of transcendent project is possible<sup>21</sup>. Thompson suggests that the acts of violence that accompany contemporary social movements<sup>22</sup> could be explained and interpreted by drawing on Marcuse's observations about "repressive desublimation": "Reviewing Marcuse's comments makes clear that, whatever his misgivings about "aggressiveness" as an outgrowth of repressive desublimation, he was open to considering violence a productive social force. Indeed, he maintained that this force needed to be protected from bourgeois ethics and representational politics. In the hands of constituted power, violence becomes the means by which the status quo is endlessly reproduced. By seizing hold of violence in a moment of Great Refusal, insurgent forces signal the possibility that another production is possible. Society is repolarized, and one-dimensionality dissolves" [7; p.175].

## **MARCUSE'S RENAISSANCE: A REPORT**

Herbert Marcuse's works have been highly influential during the sixties not only within academic circles but among wider public as well. His best known works *Eros and Civilization*, *One-Dimensional Man*, *An Essay on Liberation*, *Repressive Tolerance*, just to list a few, were not only highly critical of everything that comes out of capitalism and soviet's socialism, but also contained concrete, practical, guidance for liberation and emancipation. Hence, Marcuse's works provided manifesto for the New Left and other movements in the sixties<sup>23</sup>. As is with every living philosophy, Marcuse's opus was provocative. It was provocative by its concrete historical orientation, by its criticism and overcoming of any dogmatism. However, since the sixties the presence of Marcuse's works worldwide has steadily faded<sup>24</sup>. The exception is the US where the International Herbert Marcuse Society organizes bi-annual conferences that attempt to revalorize Marcuse's thought in the light of contemporary discussions and problems<sup>25</sup>. The journal *Radical Philosophy Review* published four issues (2013, 2016 and 2017) devoted to Marcuse studies.

There is a wide body of literature written on Marcuse's critical theory. To list them all and to provide an outline of each book would go beyond the scope of the topic<sup>26</sup>. Large part of the literature is dated in the 60s, 70's and 80's and in the 90's there is a slow decline in literature. This, of course could be explained in terms of Marcuse's popularity gained first with *Eros*

*and Civilization* published in 1955 and then with *One-Dimensional Man*. Social movements of the '68 also contributed to the fast growth of literature about Marcuse. However, it was not until 2000s that Marcuse's ideas came again into focus through various books and articles. This sudden wake of the interest is explicable again in terms of the rise of new social movements and protests<sup>27</sup>. It should be noted that recent books published about Marcuse are sympathetic towards his critical theory. In a sense authors of those books use some of Marcuse's key notions and attempt to build upon them new criticism of capitalist mode of production and everything that comes out of it. However, works that are critical to Marcuse's theory were published as well. Most of those works were published while Marcuse's fame was at its pinnacle. Current literature completely omits this fact and hence leaves critique of the 70s and 80s completely untouched and undealt with. It is easy to overlook the fact that past mistakes made by critics, if left undealt with, could once again do injustice not only to the rediscovery of some of Marcuse's most progressive ideas but to the authors who continue to work under Marcuse's critical theory. Past can repeat itself: in the past MacIntyre's, Schoolman's and Vivas' criticism easily mislead those who were unfamiliar with Marcuse's complete opus and this may reoccur today since the sudden "rediscovery" of Marcuse could prompt up "rediscovery" of criticism. Moreover, Schoolman and Vivas published their books after Marcuse's death in 1979 and thus Marcuse was denied a chance to respond to their criticism. Hence, I proceed to examine criticism and try to respond to it in an attempt to extricate Marcuse's ideas from misconceptions that are even today associated with some of Marcuse's ideas. One could assume that this attempt undertaken in the *Main Flaws of the Critique of Marcuse*, if successful would be beneficial to those contemporary authors who are interested in Marcuse's critical theory.

For the purpose of this *Report* only those books published in recent years and by the authors whose bibliography demonstrates familiarity with Marcuse's works, will be listed.

Reitz's book *Ecology and Revolution (E&C)*, published in 2018, "is grounded in the Frankfurt School critical theory of Herbert Marcuse. Its task is to understand the economic architecture of wealth extraction that undergirds today's intensifying inequalities of class, race, and gender, within a revolutionary ecological frame. Relying on newly discovered texts from the Frankfurt Marcuse Archive, this book builds theory and practice for an alternate world system. Ecology and radical political economy, as critical forms of systems analysis, show that an alternative world system is essential – both possible and feasible – despite political forces against it. Our rights to a commonwealth economy, politics, and culture reside in our common works as we express ourselves as artisans of the common good. It is in this context, that Charles Reitz develops a Green-CommonWealth Counter-Offensive, a strategy for revolutionary ecological liberation with core features of racial equality, women's equality, liberation of labor, restoration of nature, leisure, abundance, and peace" [9; p.iii].

Miles' [25] book is not recent but it should be mentioned since it provides a detailed account of Marcuse's aesthetic theory and its relation to liberation.

Any *Report* on Marcuse would be incomplete without mentioning Kellner's [2] book *Herbert Marcuse and the Crisis of Marxism* published in 1984. Kellner's book can serve as an excellent introduction to Marcuse's critical theory since it covers almost all of Marcuse's works and essays. The book also has significance since in it Kellner meticulously demonstrates Marcuse's lifelong commitment to Marxist project. Kellner's successful intention refutes those critics who questioned Marcuse's Marxist orientation and who failed to grasp that even though Marcuse abandoned Marxist orthodoxy<sup>28</sup> (Marcuse belonged to the Western Marxism current) he nevertheless remained committed to saving Marxist project.

Editorial book by Lamas, Funke and Wolfson [16] *The Great Refusal: Herbert Marcuse and Contemporary Social Movements* published in 2017 offers an analysis of contemporary social movements in reference to Marcuse's concept of "great refusal". The book chapters analyze "... different elements and locations of the contemporary wave of struggle, drawing on the work and vision of Marcuse in order to reveal, with a historical perspective, the present moment of resistance. Essays seek to understand recent uprisings – such as the Zapatistas in Mexico, the Arab Spring, and the Occupy movement – in the context of Marcuse's powerful conceptual apparatus. The Great Refusal also charts contemporary social movements against global warming, mass incarceration, police brutality, white supremacy, militarization, technological development, and more, to provide insights that advance our understanding of resistance today" [26].

Another editorial book *Marcuse in the Twenty-First Century: Radical Politics, Critical Theory, and Revolutionary Praxis* published in 2017 by Kirsch and Surak draws on Marcuse's critical theory in order to imagine possible spaces for resistance and liberation in the late capitalism.

*Crisis and Commonwealth* a book edited by Reitz in 2013 engages Marx's and Marcuse's theories in relation to future freedoms, justice and liberties. Contributing authors attempt to link Marcuse's ideas to the creation of intercultural commonwealth: "The collection extends the critical theories of Marcuse and Marx to an analysis of the intensifying inequalities symptomatic of our current economic distress (...) a labor theory of ethics and commonwealth, and the collection breaks new ground by constructing a critical theory of wealth and work. A central focus is building a new critical vision for labor, including academic labor. Lessons are drawn to inform transformative political action, as well as the practice of a critical, multicultural pedagogy, supporting a new manifesto for radical educators ..." [26].

An interesting publication is *The Dunayevskaya-Marcuse-Fromm Correspondence, 1954-1978: Dialogues on Hegel, Marx, and Critical Theory*, edited by Anderson and Rockwell in 2012 [27]. The private correspondence from August 8<sup>th</sup> 1960 corroborates what Müller [28] and Višić [29] argued that *Soviet Marxism* occupies a place within Marcuse's main current of thought even though in an interview given to Kellner [2] Marcuse claimed the opposite. The Dunayevskaya-Marcuse correspondence debates Marxist dialectics and Hegel's absolute idea.

Besides the books on Marcuse and editorial books with various contributors to Marcuse's legacy, recent years have witnessed publication of Marcuse's previously unpublished essays<sup>29</sup>. The publication of these previously unknown essays marks an epochal brake in studies of Marcuse. These essays are essential for they hold the key for understanding some of Marcuse's most prominent ideas. The origin of Marcuse's ideas lies precisely in his early writings. Thus, publishing these essays contributes to studies of Marcuse in a sense that one can easily trace genealogy and development of his ideas, how they changed in accordance to historical situation and how they permeated his whole thought. They shed a new light on "old concepts and ideas". In this respect these essays are unavoidable for any serious study of Marcuse's critical theory. An example of this is *Transvaluation of Values and Radical Social Change: Five New Lectures, 1966-1976* edited by Jansen, Reitz and Surak. This edition contains Marcuse's essays on art, radical social change, protest and rationality of philosophy. In a word they offer an insight into ideas of "new sensibility" and "transevaluation of values". *Paris Lectures at Vincennes University, 1974: Global Capitalism and Radical Opposition* edited by Jansen and Reitz in 2015 "advances Marcuse scholarship by presenting seven newly discovered, hitherto unpublished, lectures to students at Vincennes University, a branch of the Sorbonne. Marcuse's critical analysis focuses on core features of American

society, its political economy, its culture, and the potential attainability of a free socialist future” [26]. However, the most comprehensive project in this respect was the publishing of Marcuse’s collected papers in six volumes: vol. I: *Technology, War and Fascism*, vol. II: *Towards a Critical Theory of Society*, vol. III: *The New Left and the 1960s*, vol. IV: *Art and Liberation*, vol. V: *Philosophy, Psychoanalysis and Emancipation* and vol. VI: *Marxism, Revolution and Utopia*. Publications of these volumes that contain previously unpublished and unknown Marcuse writings mark an attempt to reintroduce Marcuse to contemporary discourses<sup>30</sup>. The essays assembled in these volumes provide fresh into Marcuse’s works and further advances studies of Marcuse’s critical philosophy. As has been mentioned earlier, these volumes should not be read as an (extra) addition to Marcuse’s main works but as an accompanying texts that offer a deeper insight into some of Marcuse’s ideas. For better understanding of Marcuse’s ideas and theory these texts sometimes prove to be more relevant than some of his more famous writings.

From the *Report* presented here one could note that the Marcuse renaissance began in the English speaking part of the world. Books about Marcuse are predominately being published in the US. Besides the obvious reawakening of the interests for Marcuse’s ideas this could be ascribed to the fact that some of Marcuse’s students became university professors and continued to safeguard the (revolutionary) legacy of their professor Marcuse<sup>31</sup>.

However, there are indications, judging by the published books, that academicians from other part of the globe are interested in reintroducing Marcuse’s legacy. Italian author Renata Bascelli published *Per una filosofia concreta: Alle radici del pensiero di Marcuse* in 2018: “The need for a ‘concrete philosophy’ is the reason that constantly inspires the reflection of Marcuse, from the first writings (...) up to the later works (...) The thought of Marcuse, from its origins, in virtue of the lucid vision that characterizes it, can still constitute a lesson for the contemporary world and (...) perhaps try to solve, the total crisis that is gripping humanity today” [26]. Similar attempt was made by the author of this study in the book *Critique and Resistance: Foundations of Herbert Marcuse’s Critical Philosophy* (In Croatian) published in 2017. Reviewing the book Buzar writes: “It is a work that (...) is apparently written with the intent of encouraging new-old views of the socio-political and economic reality of modern man (...) The primary focus is Marcuse’s thought and his concept of revolution. Therefore, it is, of course, not an invitation for a revolution, but an invitation for ‘breakthrough of thought’, about how the notions of ‘revolution’ and ‘freedom’ should be thought of” [31; pp.193-194]. Portuguese Luis Gustavo Guadalupe Silveira published in 2011 a book on Marcuse’s aesthetics *Alienação artística: Marcuse e a ambivalência política da arte*. In Germany Tim B. Müller published in 2010 a book *Krieger und Gelehrte: Herbert Marcuse und die Denksysteme im Kalten Krieg*. The book explores Marcuse’s (among others) engagement during Cold War with US secret services arguing that Marcuse’s critique of Western modernism may come from the period of his involvement with intelligence agencies.

The existing body of literature written about Marcuse is by no means exhausted in this *Report*. For the *Report* only established and prominent Marcuse scholars have been chosen, who, unlike critics, are familiar with Marcuse’s life work. However, Marcuse’s critics have also (un)contributed to the literature and hence the next section will assess and revalorize their share.

## MAIN FLAWS OF THE CRITIQUE OF MARCUSE

During its heyday in the sixties Marcuse’s works provoked significant criticism. However, it should be said that Marcuse gained fame with his later works, namely *Eros and Civilization* and *One-Dimensional Man* originally written in English language and during his living in the US. Before this “sudden” burst of fame, Marcuse was largely unknown figure in the

academia. Hence, his pre-war works written and published in Germany remained largely unknown and due to the language barrier, unviable to the wider public. It is only after he gained popularity that his complete works were translated into English language and hence available to his critics and sympathizers. Unfortunately, this delay in translations will prove to be fatal for almost all of Marcuse's critics. Negative criticism, as was to be expected, focused largely on Marcuse's latter works, completely omitting his early works (or mentioning them only marginally) which are in fact crucial for understanding Marcuse's complete critical theory. Thus, flaws in criticism results from the unfamiliarity with Marcuse's pre-war (or pre-emigration) writings<sup>32</sup>. It is curious to note that while one can still find some recent articles and books on Marcuse (mostly affirmative), there is a complete lack of articles and books critical to Marcuse's ideas.

Marcuse's most prominent critics worth mentioning are MacIntyre, Schoolman and Vivas. The reason why they are worth engaging with is that all of them assert that they are ("allegedly") familiar with Marcuse's complete works<sup>33</sup>. The problem with negative criticism is on two levels: at the level of content and at the level of form. Apart from the objections that could be raised on the content of the criticisms and disputability of critic's interpretations, the problem lies in the very form in which criticism is presented. MacIntyre proceeds thorough criticizing Marcuse's and commits himself to "exceptional obligation to portray what Marcuse says faithfully" [34; p.7]. Even though he acknowledges the importance of Marcuse's early writings<sup>34</sup>, it is interesting that MacIntyre starts his critique completely omitting important essays<sup>35</sup> such as: *Philosophy and Critical Theory*, *On the Concept of Essence*, *On Concrete Philosophy*, *On the Philosophical Foundations of the Concept of Labor*, etc. [29]. This "thorough" critique of Marcuse's positions MacIntyre carries out on the 92 pages. It is practically impossible to deliver a thorough critique on 92 pages, especially on Marcuse whose complete opus is quantitatively impressive and qualitatively complex [29]. MacIntyre himself admits this: "The criticism of Marcuse's positions encounters two kinds of difficulty; those posed by particular theses which he asserts and those posed rather by his whole manner of thought and style of presentation. Marcuse's manner is both literary and academic; he is allusive and seems to presuppose in his readers not only a high level of general culture, but a wide area of presumed agreement on academic matters (such as the interpretation of Descartes – to give one example)" [34; p.17]. Hence, one could argue that it is impossible to deliver a thorough critique on 92 pages that MacIntyre announces. Without reflecting on Heidegger's, Marx's and Hegel's influence on Marcuse it is possible to deliver a general, reductionist and seriously flawed critique. Schoolman's [35] intention is also to conduct a systematic and comprehensive critique and exposition of Marcuse's complete works: "in the sense that it attempts to discover the conceptual limits of his theoretical framework, to account for the origins of these limits, and to demonstrate how his arguments are shaped within and by this framework (...) The account that I offer for what I contend to be his errors implicitly serves to extricate Marcuse from the harsh indictments that have been leveled in the past" [35; p.xiii]. Schoolman, whose criticism is also flawed, is aware of the existing misconceptions about Marcuse's positions: "Marcuse was constantly on the defensive against his accusers and supporters, who both frequently attributed views to him that he did not hold. Seldom was *criticism* forthcoming" [35; p.xi]. However, Schoolman's initial intention failed to realize and to deliver on its promise to extricate Marcuse. The problem with Schoolman's criticism (at the level of form) is that throughout the entire book, Schoolman (usually wrongly) presents Marcuse's thesis and ideas by paraphrasing them without quoting or referencing to the original texts [29]. Moreover, Schoolman recounts and summarizes the ideas of Heidegger, Freud and Lukács again without indicating where these ideas could be found in the original texts [29]. Finally, Schoolman mentions Marx passingly

without giving any deep significance to Marx's ideas that shaped and influenced Marcuse's critical philosophy. Hence, from Schoolman's un-academic approach to the subject it is not possible to see clearly whose ideas influenced Marcuse and how [29]. On the opposite pole of negative criticism stands Vivas whose criticism contains a dose of non-justified and non-grounded "enmity" towards Marcuse's ideas<sup>36</sup>. In his "savage" (to use his own term) criticism of Marcuse, the conservative professor of philosophy<sup>37</sup> Vivas announces the tone of his criticism as well as his contribution to the existing body of literature: "This is a polemical essay, directed at Marcuse's savage indictment of our society. It is not offered as an academic contribution. It has not been couched in the third person language that is loved by academics (...) it often uses the first personal pronoun, and when it does not call a spade a spade, it refers to it as a manure shovel. It does not quite get down to the level of the academic New Left; it uses euphemism like 'manure' instead of the four-letter words that are frequently found in the writings of the new nihilists, both among academics and among students. I refrain from such language not because I'm ignorant of four-letter words, but because that kind of language (...) ought not to be allowed to lose its value by everyday usage" [33; p.9]. From the quoted passage it is possible to assume the extent to which Vivas' criticism is appropriate, written with objective distance and finally how it contributes critical examination of Marcuse's theory. Moreover, the quoted passage testifies to its intention and purpose. Unlike MacIntyre and Schoolman who at least recognized erudition and complexity that imbues all Marcuse works, Vivas assumes that it is possible to give comprehensive critique by superficial reading of his works: "One does not have to read him extensively to learn that from his pages arises an asphyxiating vapor, corrosive in its animosity" [33; p.22]. Assuming that this enterprise is possible Vivas acknowledges the ignorance and superficiality of his own criticism: "In the book I have not done more than assert in general terms that some of his criticism is without foundation ..." [33; p.10]. Lacking in depth knowledge, Vivas' critique of Marcuse dismantles itself from the inside.

Let us summarize the problem of Marcuse's criticism at the level of the form. All mentioned critics are aware of the importance of Marcuse's early essays and they clearly state that fact. However, this very fact proved not to be useful in their critical endeavour. It is evident that even though mentioned critics claim familiarity with early writings, they either completely skip the early phase (MacIntyre), or poorly and wrongly summarize main ideas (Schoolman), or finally, completely ignore pre-war writings (Vivas). However, this omission at the formal level will have serious consequences at the level of content of criticism. Instead of opening space for improvement, the criticism has done injustice to some of Marcuse's most prominent and advanced ideas. Marcuse's views and ideas were largely influenced by Schiller, Hegel, Marx, Freud, Heidegger and (early) Lukács. Thus, for understanding Marcuse's position (even in his later works) it is of utmost importance that one should be familiar with those authors in order to comprehend what Marcuse took from them and further developed. From the form in which criticism is presented it is evident that the mentioned critics lack familiarity with some fundamental ideas of the authors that influenced Marcuse. The problem is that nobody seriously dealt with criticism and this in turn has led to the accumulation in the body of criticism by repeating what has already been (wrongly) said about Marcuse's critical theory. In the next passages I will attempt to respond to criticism.

Vivas apologetically and without any imagination glorifies the established "reality principle" and "performance principle" arguing that the model of Western societies should be implemented to other less developed societies: "We live in a better world, we fortunate ones, that man has probably ever lived in before. The majority of our citizens, and a large number of members of Western society outside the borders of US, enjoy opportunities that only a small minority ever enjoyed before. And we are earnestly seeking to expand the number of

people who can enjoy this opportunities, in and out of the US” [33; p.19]. If Vivas had any imagination in Marcusean sense of the word<sup>38</sup>, he would be able to imagine a qualitatively different world that can arise on the basis of the existing one. Vivas then proceeds to argue that Marcuse is advocating total annihilation of the society: “... his call for the destruction of our society, for direct action, for the shooting and murdering and repression of those who do not see the world with the hate filled eyes he sees it with ...” [33; p.9]. Had Vivas thoroughly read Marcuse he would have realized that there is no mentioning of destruction of established society (as that would be inappropriate to Marcuse's Marxist understanding of history) but only of dialectical overcoming which is something completely different.

MacIntyre is uncertain about Marcuse's criteria of truth (which is significant in Marcuse's theory as an assessment of that what it is in terms of that what could be): “Marcuse at various points both in these early writings and later on refers to criteria of truth which he rejects. But he does not make it clear what criteria of truth he accepts or to what criteria of truth he is appealing in inviting us to accept his assertions” [34; pp.17-18]. For Marcuse the only criterion of truth is the reality of reason from the perspective of concrete historical possibilities<sup>39</sup> [29]. To answer MacIntyre it is not necessary to reference all positions from which Marcuse's lifelong preoccupation with reality of reason is evident. As an answer to MacIntyre, a summary of Marcuse's criterion of truth will suffice: “(1) The transcendent project must be in accordance with the real possibilities open at the attained level of the material and intellectual culture. (2) The transcendent project, in order to falsify the established totality, must demonstrate its own *higher* rationality in the threefold sense that (a) it offers the prospect of preserving and improving the productive achievements of civilization; (b) it defines the established totality in its very structure, basic tendencies, and relations; (c) its realization offers a greater chance for the pacification of existence, within the framework of institutions which offer a greater chance for the free development of human needs and faculties. Obviously, this notion of rationality contains, especially in the last statement, a value judgment, and I reiterate what I stated before: I believe that the very concept of Reason originates in this value judgment and that the concept of truth cannot be divorced from the value of Reason” [13; pp.224-225]. Another correction that needs to be done relates to MacIntyre's classification of Marcuse as a “pre-Marxist” thinker [29]. MacIntyre bases this classification on two observations: 1) “He sometimes speaks not of Marxist materialism but of ‘the critical theory of society’ ” and 2) “Marcuse is endlessly willing to talk of ‘man’ rather than of men, of what ‘man’ desires or does or suffers” [34; p.21]. Moreover, MacIntyre assumes that Marcuse pertains to young Hegelians rather than to Marxism: “The hypothesis that it is with the Left or Young Hegelians that Marcuse has to be classified is reinforced by the way in which he treats Hegelian theory and even its Marxist version as providing us with standard of rationality against which the actual world must be judged” [34; p.40]. Marcuse's Marxism was marked by constant search for revolutionary subject that is capable of transforming given reality. It is correct that Marcuse gave up proletariat once he noticed that proletariat has become integrated into mass society, or in other words, subordinated to the “technological rationality”. However, it is utterly inappropriate (and incorrect) to call Marcuse “pre-Marxist” or “non-Marxist” since Marcuse's complete approach is carried by Marxist open dialectic which essentially contains the notion of necessity and demonstrates that laws of capitalist mode of production contain internal antagonisms whose overcoming has the character of necessity [29]. For Marcuse, capitalism abolishes itself in the dynamics of internal antagonisms. This abolishment is not carried out by inherent necessity but by “spontaneity of reason” (and here we can see the openness of Marxian dialectic), and by achieved level of material, technological and intellectual development. Subsequently, at the center of Marcuse's concept of liberation lies the notion of labor in its Marxist meaning. Marcuse assumed that due to the technological development it

is possible to reduce time spent at labor and increase the time in which human being can comprehensively develop his being. Finally, what makes Marcuse distinctive to other Marxist is that for him the beginning and the goal was liberated individual and not class<sup>40</sup>.

Schoolman argues that Marcuse's concept of radical social change is more directed to the level of cognizance: "Marcuse, it must be emphasized, is not speaking in these very important passages of the actual destruction or abolition of alienation, reification, and the social relations from which this condition arises. On the contrary, Marcuse is speaking of a *cognitive* act, of an act of *understanding*, of the impulse *upon* which the act of abolition, of social revolution, is eventually to be based" [35; p.25]. However, Schoolman's claim is utterly dubious. First and foremost, Marcuse understood repression to be socially conditioned and hence the process of overcoming could not be conceived as cognitive act. Quite contrary, Marcuse clearly expressed that these conditions could not be overcome by cognition: "... not as subjective properties that could be overcome by understanding concern but rather as the effects of the intervention of social necessities into the personal sphere" [38; p.123]. It is precisely in the early works where Marcuse conceived radical act as an act that aimed to appropriate reality that seems foreign to human being. Following this, Marcuse will later define "great refusal" as the protest against "surplus repression", against dominant norms, as a struggle for final form of freedom. Therefore it is not clear on what arguments Schoolman bases his claim equating radical act with cognitive act. Moreover, freedom for Marcuse is the freedom from the "kingdom of necessity".

Problematic as well is Schoolman's interpretation of Marcuse's concept of critical theory. Schoolman argues: "What this means is that critical theory becomes emphatically 'theory'; that is it articulates its goals, its truth, without reference or direct appeal to a practical agent of historical change for that agency is no longer a conscious revolutionary subject (...) Critical theory especially retains its theoretical allegiance to political economy because materialism is the basis of its concept of essence and identifies structural tendencies in the social system that can lead to radical change (...) Claimed to exist independently of any subject's failure to comprehend them, transcendent possibilities become, as Marcuse says, critical theory's utopian element" [35; pp.72-73]. Suffice is to outline some problematic points in Schoolman's interpretation. The "practical agent" (or the subject) of Marcuse's critical theory that is missing according to Schoolman, is always ordinary, everyday individual in his concrete historical situation and in his concrete world. Hence, the critical theory (as well as "concrete philosophy") appeals to an individual by indicating to him possibilities for better life and for self-confirmation in the world that he has created and to which he belongs. Schoolman asserts that critical theory owes its allegiance to political economy. However, Schoolman is wrong since Marcuse defined critical theory in clear distinction to philosophy, sociology and political economy [29]. In addition Marcuse demonstrated how critical theory surpasses political economy: "The difference lies in the decisive factor, precisely the one that makes the society rational – the subordination of the economy to the individuals' needs" [36; p.106]. Final disputable point in Schoolman's interpretation relates to the element of utopia. Marcuse did not consider the possibilities of critical theory to be utopian. Instead, he asserted that critical theory along with philosophy opposes any type of positivism. What differentiates critical theory from philosophy is its insistence on qualitative change which is always derived from social tendencies and not by confrontation of some utopian vision: "Like philosophy, it opposes making reality into a criterion in the manner of complacent positivism. But unlike philosophy, it always derives its goals only from present tendencies of the social process. Therefore it has no fear of the utopia that the new order is denounced as being. When truth cannot be realized within the established social order, it always appears to the latter as mere utopia. This transcendence

speaks not against, but for, its truth. The utopian element was long the only progressive element in philosophy, as in the constructions of the best state and the highest pleasure, of perfect happiness and perpetual peace (...) Critical theory preserves obstinacy as a genuine quality of philosophical thought" [36; pp.105-106].

Especially astonishing is Schoolman's assertion that after early works and due to the experience of fascism Marcuse completely abandoned his concern for an individual<sup>41</sup>: "Fascism was that political event (...) that eventually led to Marcuse's abandonment of the individual" [35; p.37]. This astonishing assertion will completely mislead Schoolman to conclude that the subject of critical theory is imaginary "Critical theory, its knowledge of the society and of its alternatives, becomes the property of an imaginary witness, of an individual who no longer exists. The imaginary witness, however, is the mournful and melancholy legacy of a critical spirit born from the horrors of fascism" [35; pp.350-351]. It is not clearly evident what made Schoolman to arrive to this (wrong) conclusion; especially since Marcuse's complete work could be described from its preoccupation with an individual and for creation of a more humane world. Furthermore it was precisely the experience of fascism that led Marcuse to believe that a new anthropology of human being is necessary prerequisite for a new society which he expressed through notions "new rationality" and "new sensibility"<sup>42</sup> [29]. Contrary to Marcuse's conscious subject who lives in harmony with reason and *eros*, Schoolman posits an "ambivalent individual" as the subject of critical theory: "Only a theory that recognizes the effects of reification and realizes that the structure concealed by ideology generates insights that transcend appearances can be a radical theory. Such a theory is radical because it recognizes that the individual is necessary ambivalent" [35; p.352]. However, Schoolman's "ambivalent subject" is not capable for taking radical act precisely because of this ambivalence that is immanent to him. His ambivalence bonds him to the same "principle of reality" and "pleasure principle" against which Marcuse directed his criticism. It is important to emphasize that Marcuse's subject is the result of a dialogue with Freud (interplay of two life instincts: *eros* and *thanatos*), Marx (human beings as a species beings; labor as a free human activity that leads to all-around self-realization), Schiller (*homo ludens*, aesthetic education) and Heidegger (*Dasien's* thrownness into the world, radical act, authenticity)<sup>43</sup>.

Schoolman completely misunderstood Marcuse's appropriation of Freud's ideas as on the example of the two basic instincts *eros* and *thanatos* [29]. This is mostly evident in Schoolman's reductionist and banal account of Marcuse's approach to art: "Libidinal rationality is still socialism's guiding principle. But Eros is no longer entrusted to the vicissitudes of political practice, no longer vested in the erstwhile politics of the New Left's new sensibility. Eros finds a new and sublimated refuge in art" [35; p.326]. However, few points will be sketched here as well. Marcuse accepts the thesis of the "permanence of art" and thus sees the activity of *eros* and art immanent to human beings as a species in its struggle against "surplus repression" regardless of the historical situation. Schoolman's account that for Marcuse the modern art is conformist is erroneous due to his ignorance: "Modern art is conformist. It sacrifices the truth of the aesthetic dimension by transforming art into a language and experience that affirms and supports the established social order. Form, modern art contends, is a deadly obstacle to the artist's search for an aesthetic presentation of modern civilization that will display its horrors and spiritual poverty (...) As form disappears from art, art's critical disposition and the aesthetic dimension recede in proportion. Art is assimilated into the fabric of one-dimensional society" [35; p.344]. However, for Marcuse the conformist art is only mass art that Marcuse terms as "anti-art" meaning the art that has been commodified<sup>44</sup>. As an answer to Schoolman it is suffice to quote Marcuse from his essay *Art as Form of Reality* in which he clearly demonstrates an advanced moment of modern art : "I believe that the authentic avant-garde of today are not

those who try desperately to produce the absence of Form and the union with real life, but rather those who do not recoil from the exigencies of Form, who find the new word, image, and sound which are capable of 'comprehending' reality as only Art can comprehend—and negate it. This authentic new Form has emerged in the work (already 'classic') of Schönberg, Berg, and Webern; of Kafka and Joyce; of Picasso; it continues today in such achievements as Stockhausen's *Spirale*, and Samuel Beckett's novels. They invalidate the notion of the 'end of art' " [41; p.146].

What is perhaps most misunderstood by critics is Marcuse's approach to technology as the new subject of social change<sup>45</sup>. The extent to which MacIntyre misunderstood how technology fosters integration of individuals into society is evident from the following passage: "It is clear that technological advance and investment in such advance are the mainspring of the continuous expansion which underpins the real if precarious stability of advanced industrial society. This expansion affects to some degree every sector of the social order. But the degrees to which different sectors are affected, the rates at which they expand and the directions in which they expand are quite different. The result is not the highly integrated and well-coordinated system portrayed by Marcuse, but rather a situation in which there is less and less coordination between different sectors" [34; p.70]. Schoolman, on the other hand, confuses concepts. He interchangeably and confusingly uses concepts of "technological rationality" and "technological domination"<sup>46</sup>. It should be emphasized that within Marcuse's critical theory there is no such concept as "technological domination". Furthermore, Schoolman never defined how "technological domination" could be related to Marcuse's theory and besides that he wrongly interprets the "technological rationality": "Simply stated, whenever Marcuse speaks of technological rationality he is referring to the modus operandi of the process of material production. He appears to construe production in the broadest possible sense: all sectors of industrial enterprise – the whole military-industrial complex, as well as the entire distributive network of goods and services – are included" [35; p.140]. However, this is not "technological rationality" as used by Marcuse. Marcuse defines "technological rationality" in distinction to individual rationality; arguing that under the influence of technological apparatus the latter is transformed into former. Hence, for Marcuse "technological rationality" determines not only the way in which individuals think but the forms of protests and revolts. Thus, technological rationality, the way Marcuse uses it, describes the prevailing mode of thinking and acting – of being-in-the-(technological)-world. Schoolman, also, fails to notice that "technological rationality" holds subversive potential on which Marcuse based his argument about cooperation of technology and art in creating the new society: "The technological rationality also contains an element of playfulness which is constrained and distorted by the repressive usage of technology: playing with (the possibilities of) things, with their combination, order, form, and so forth. If no longer under the pressure of necessity, this activity would have no other aim than growth in the consciousness and enjoyment of freedom. Indeed, technical productivity might then be the very opposite of specialization and pertain to the emergence of that 'all-round individual' who looms so large in Marxian theory" [43; p.257]. Another criticism comes from Kołakowski according to whom: "Marcuse's thought is a curious mixture of feudal contempt for technology, the exact sciences, and democratic values, plus a nebulous revolutionism devoid of positive content (...) The destructive effects of science are inherent in its content and are not simply due to its social misapplication (...) Marcuse's attacks on science and logic go hand in hand with attacks on democratic institutions and 'repressive tolerance' (the opposite of 'true' tolerance, i.e. of repressive tolerance" [44; pp.416-417]. Quite contrary to Kołakowski's argument, Marcuse did not assume that destructive relation to humans and to nature is immanent to technology<sup>47</sup>. Marcuse was not a technophobe as Schoolman and Kołakowski try to portray his views on technology. Transcendence of existing society is

possible only by rearrangement in technological base. Hence, “feudal contempt for technology” does not quite capture Marcuse’s position or views.

With this criticism is, to a certain extent and in its main points, exhausted. As has been argued, the problem of the critique of Marcuse is twofold: at the level of form and at the level of content. Marcuse became widely known with his later works (*E&C* and *ODM*) which alongside acclamation produced negative criticism as well. Criticism in this sense focused mainly on Marcuse’s later works while completely omitting (or only passingly mentioning) his early works. In a way, Marcuse’s later works are just an elaboration and further development of his main ideas laid down in his early writings (and to a certain extent, an accommodation of those ideas to a wider public that was in a sense unfamiliar with continental philosophy)<sup>48</sup> laid down in his early writings. Thus in order to understand what Marcuse is saying it is absolutely necessary to study his early works as they hold the key for comprehending his later works and ideas in general. Critics may be partially excused since Marcuse’s pre-war writings were translated later. However, the damage has been done and until now there has not been any serious attempt to extricate Marcuse’s ideas from various misreadings. Hence, these lapses in criticism became commonly accepted and the future critique of Marcuse’s works continued to build on this widely but wrongly shared opinions. Marcuse’s texts represent but a genuine commitment to the historical possibility of a better world. Critique has pointed to some flaws in Marcuse’s theory, but an in-depth insights and substantiality is lacking. Most of Marcuse’s ideas are de-contextualized which renders such critique of Marcuse flawed. Among critics there is insufficient understanding of interdisciplinary of Marcuse’s critical theory and especially of the influences that Heidegger, Hegel, Schiller, Marx, Freud and Lukács had on Marcuse.

## **CONCLUDING REMARKS**

Let us end with a couple of concluding remarks. It is our belief that recent social struggles and political upheavals point to the potential of Marcuse’s critical theory to offer guide to the contemporary *praxis*. Re-emerging academic interest in Marcuse testifies to the relevance of Marcuse for contemporaneity. Although recently published books are positively inclined towards Marcuse, there is no systematic attempt to respond to negative criticism. That leaves Marcuse’s most progressive ideas vulnerable to the same flaws that could be identified in the critique already done in the past. In this study we have done our best to amend this fact. To conclude on Marcuse’s renaissance only one word written on Marcuse’s gravestone comes to mind: “weitermachen!”

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## **REMARKS**

<sup>1</sup>Marcuse’s deeper and more substantial closeness to Heidegger can be seen in the *Heideggerian Marxism* collection of essays. This is most evident in the essays *Contributions to a Phenomenology of Historical Materialism* and *On Concrete Philosophy*.

<sup>2</sup>Marcuse introduces the notion of “historical project” in an attempt to substitute the foundation of historicity in the ontology of labor.

<sup>3</sup>Marcuse articulated this criterion in the essay *Philosophy and Critical Theory*.

<sup>4</sup>Namely two epochs: first, pre-technological in which one needed to constantly struggle with nature to secure existence and thus labor had burdensome character. And second,

technological epoch in which technological development could render labor obsolete or at least reduce it to the minimum.

<sup>5</sup>It should be noted that in Marcuse's later writings "world" is interchangeably used with "society".

<sup>6</sup>As Marcuse writes in recently discovered *Paris Lectures*: "What is actually happening at this stage of capitalist development is not the emergence of a new working class but a vast extension of the working class, an extension of the working class to strata of the middle classes which at previous stages of capitalism have been independent" [4; p.46].

<sup>7</sup>As Aronowitz explains: "Although *Eros and Civilization* is written, in the main, in philosophical and theoretical terms, it is essential to place Marcuse's work not only in the twentieth century outpouring of psychoanalytic thought, but also in the nineteenth and twentieth centuries' philosophical intervention to put philosophy back into the world and in the realm of the concrete" [5; p.133].

<sup>8</sup>In this respect Marcuse could be included among founders of bioethics. As Reitz points out: "Marcuse regarded the environmental movement of his day as a critical intervention against institutional destructiveness and as the embodiment of a life-affirming energy directed towards the protection of Earth and the pacification of our human existence" [6; p.163].

<sup>9</sup>As Reitz comments: "Marcuse saw within the classical liberal arts philosophy critical impulses toward multiculturalism, social history, and critical social theory (...) He also (...) shares (...) the philosophical conviction that the most meaningful and beautiful works of art are also the soundest foundation for an education to political justice" [6; p.88].

<sup>10</sup>Which according to Reitz proves to be of utmost significance for present situation: "... if we all have a de jure right to express any opinion in public, the de facto condition is that left opinions are usually marginalized and often suppressed, while right-wing ones, which benefit the ruling class, are given free play" [6; p.18].

<sup>11</sup>See *Main Flaws of the Critique of Marcuse*.

<sup>12</sup>And in this respect Hegel's, Freud's, Schiller's, Heidegger's, Lukács' and Marx's influence on Marcuse will be evident.

<sup>13</sup>See *Marcuse's Renaissance: A Report*.

<sup>14</sup>See Matušík's article *The Existential Dimension of the Great Refusal: Marcuse, Fanon, Habermas*. In the article Matušík attempts to demonstrate theoretical closeness of Marcuse, Fanon and Habermas.

E.g.: "If one refigures Marcuse's refusals through Fanon's existential inventions, leaps can serve to link transgressive singularities with personal and global agencies of liberation (...) A concrete critical theory of liberation today gathers refusing voices from multiple margins. This thought can deliver on an earlier promissory note that democracy-to-come must become morally and sociopolitically anticolonial and ethically postcolonial" [11; p.320]. Matušík asserts: "Marcuse's essays (1928-1932) serve the young Habermas to become more concrete in a twofold sense: to move away from abstract historicity and to move closer to historical and material analysis with practical intent (...) Habermas's sociopolitical version of the either-or self-choice, influenced by his intense intellectual engagement with Marcuse's works, thus retains its radical existential character..." [11; pp.323-326].

<sup>15</sup>Marcuse dedicated *An Essay on Liberation* to the protesters who took to the streets of Paris.

<sup>16</sup>In this respect it could be said that Marcuse identifies the "great refusal" with those who belong to this democratic excess, those who live on the outskirts of democracy: "They exist outside the democratic process; their life is the most immediate and the most real need for ending intolerable conditions and institutions" [13; p.260].

<sup>17</sup>Matušík who interprets Marcuse's "great refusal" as an expression of concrete existential thought in either-or terms asserts: "If projects of liberation aim at radically multicultural

democracies with human faces, these must admit an existential dimension. This existentiality issues in a reconstructed historical materialism, not in the wasteland haunted by spiritual ghosts. Democracy concerns the entirety of human existence, or it is abstract. Revolution concerns the entirety of human existence, or it is abstract. Dissent and democracy concern the entirety of human existence, or they are abstract” [11; p.317].

<sup>18</sup>He was Marcuse's student.

<sup>19</sup>Katsiaficas develops further Marcuse's argument about instinctual drive and need for freedom. The “eros effect” is used to explain contemporary uprisings and social movements: “During moments of the eros effect, universal interests become generalized at the same time as dominant values of society (national chauvinism, hierarchy, and domination) are negated (...) Dimensions of the eros effect include the sudden and synchronous emergence of hundreds of thousands of people occupying public space; the simultaneous appearance of revolts in many places; the intuitive identification of hundreds of thousands of people with each other; their common belief in new values; and suspension of normal daily routines like competitive business practices, criminal behavior, and acquisitiveness (...) The eros effect is not simply a general strike, armed insurrection, or massive mobilization. Rather, it can be all of these and more. It is not an act of mind; nor can it be willed by a ‘conscious element’ (or revolutionary party). It involves popular movements emerging in their own right as ordinary people take history into their hands. The concept of the eros effect is a means of rescuing the revolutionary value of spontaneity, a way to stimulate a reevaluation of the unconscious” [14; p.85].

<sup>20</sup>See, e.g. [17-19].

<sup>21</sup>Vieta accurately poses a question: “Indeed, contrary to Marcuse's ultimate vision, perhaps we must question whether such ‘total’ transformations of the system can ever be achieved lest we be reduced back into hegemonic and oppressive forms of vanguardist, *etatist*, or universalist thought and practice” [20; p.278].

<sup>22</sup>E.g. black block group of protesters and other alike groups.

<sup>23</sup>Unwillingly, Marcuse was proclaimed to be father and guru of the New Left, see e.g. [21-23]. However, Marcuse refused to be called “father” or “grandfather” of the New Left. Refusal to be associated with any type of father figure can be explained from Marcuse's engagement with Freud's theory. Marcuse's investigation into Freud's theory clearly revealed that father figure (whether in family (father-son conflict) or in “primordial horde” (rebellion of the sons against dominating father who monopolizes pleasure which eventually leads to parricide)) impersonates the reality principle – the very principle that imposes restrictions on instinctual structure and that is responsible for internalization of various repressive mechanisms. One can presume that this was the key reason why Marcuse refused to be associated as the father of the New Left. He would then be an embodiment of the principle that he vigorously criticized as the hindrance to truly human liberation.

<sup>24</sup>This is especially the case of Croatia where Branka Brujić [24] obtained her Ph.D. in 1973 with thesis *Critical Theory of Herbert Marcuse and Historical Thinking* (In Croatian). However, thesis was never published as a book.

<sup>25</sup>Author of this study participated at the International Herbert Marcuse Society Sixth Biennial Conference at Salisbury University (USA) November 12-15, 2015 with written contribution *Contemporary One-Dimensional Society – Is Marcuse's Thought Still Valid?* (published in the book of abstracts).

<sup>26</sup>Complete and exhaustive bibliography on Marcuse could be found on official webpage dedicated to the legacy of Herbert Marcuse. The page is curated by his grandson dr. Harold Marcuse. The page provides detailed and up to date (from 1940s nowadays) information on books, articles and reviews about Marcuse. Complete bibliography could be seen at: <http://www.marcuse.org/herbert/booksabout.htm>.

<sup>27</sup>Reitz asserts: “Recent years have witnessed a genuine Marcuse Renaissance. *New Political Science* devoted a special issue to *Marcuse in the Twenty-First Century: Radical Politics, Critical Theory, Revolutionary Practice* (2016). The *Radical Philosophy Review* dedicated four Special Issues to fresh considerations of Marcuse’s thought (2017 and 2016; twice in 2013). Two collections of commentary on Marcuse’s political perspective have also been published in 2017, *The Great Refusal: Herbert Marcuse and Contemporary Social Movements*, edited by Andrew T. Lamas, Todd Wolfson, and Peter N. Funke, and *One-Dimensional Man 50 Years On: The Struggle Continues*, edited by Terry Maley” [9; p.3].

<sup>28</sup>I.e. giving up of the proletariat.

<sup>29</sup>Most of those essays come from the Marcuse Archive in Frankfurt.

<sup>30</sup>Kellner describes general intention of the volumes: “For while there have been a large number of new translations of works by Benjamin, Adorno and Habermas during the past decade, little untranslated or uncollected material by Marcuse has appeared. In addition, while there has been great interest in recent years in the writings of French ‘postmodern,’ or ‘poststructuralist,’ theorists, such as Foucault, Derrida, Baudrillard, Lyotard and others, Marcuse did not fit into the fashionable debates concerning modern and postmodern thought (...) The neglect of Marcuse may be altered through the publication of a wealth of material, much of it unpublished and unknown ...” [30; pp.xiv-xv].

<sup>31</sup>Or could it be perhaps that Marcuse’s project remained unfinished, or took an unappealing turn? (such as new form of dominance, in-development of technological rationality, new forms of repression and even more new forms of renunciation, occupations that are slowly dying since the humans can be replaced by the machines and thus creating a vast population that is “useless” in the new information and services society, new forms of alienated labor such as precarious labor, etc.).

<sup>32</sup>An example of misapprehension due to the unfamiliarity with Marcuse’s complete critical theory (and this applies to all critics) offers Nancy Chodrow [32] who completely misinterprets Marcuse’s appropriation of Freud’s ideas. Farr replies offering a valid reason: “Chodrow’s criticism of Marcuse is appropriate only if Marcuse’s interpretation of Freud is taken out of the context of his critical project. Marcuse’s work on Freud must be taken as only a moment within a larger more complex project” [3; p.63]. Therefore it can be said that every serious criticism of Marcuse must grasp and be familiar with his entire work.

<sup>33</sup>Both Vivas and Schoolman claim familiarity with Marcuse’s early writings as well as its significance for understanding his later works: “Not all essays in *Negations* are of equal value to the student of Marcuse’s nihilism; but those published in the Thirties are of interest because they show that Marcuse was then concerned with ideas that he was to develop later in his books (...) Professor Eric Voegelin told a mutual friend, who passed it on to me, that Marcuse has been saying very much the same thing for as long as Voegelin has known him. Some proof of the truth of the statement is to be found in these older essays” [33; p.7].

“... the early period is the most important in Marcuse’s life work“ [35; p.3].

<sup>34</sup>The importance of these early papers does not lie only in the fact that they constitute a first statement of the thesis which informs the whole of his later work. For on certain points they are more explicit than anything in the later works” [34; p.16].

<sup>35</sup>In fact MacIntyre (as well as other mentioned critics) omits all of the early essays that are collected in *Negations: Essays in critical Theory and Heideggerian Marxism*.

<sup>36</sup>Here are some examples that corroborate this “enmity”: “He does not deserve our courtesy, our charity, our tolerance (...) If he were to possess the power for a short while, he would out-Robespierre Robespierre, out-Saint-Just Saint-Just ...” [33; pp.9-10]. On one occasion Vivas implicitly calls Marcuse “a termite who gnaws civilization: He is a hero in France, Germany, Italy, and it goes without saying in Columbia University and points west, wherever in our world the social termites gnaw at the uprights of our civilization” [33; p.51].

<sup>37</sup>He declared himself conservative: "I call myself conservative ..." [33; p.11].

<sup>38</sup>In his early writings Marcuse indicated imagination (phantasy) as the key instrument of critical theory: "In order to retain what is not yet present as a goal in the present, phantasy is required (...) For it would determine what man is on the basis of what he really can be tomorrow. In replying to the question, 'What may I hope?', it would point less to eternal bliss and inner freedom than to the already possible unfolding and fulfillment of needs and wants. In a situation where such a future is a real possibility, phantasy is an important instrument in the task of continually holding the goal up to view (...) Without phantasy, all philosophical knowledge remains in the grip of the present or the past and severed from the future ..." [36; pp.113-114].

Later, in *Eros and Civilization* Marcuse again emphasizes the subversive potential of emancipation within psychoanalytic theory: "Freud singles out phantasy as one mental activity that retains a high degree of freedom from the reality principle even in the sphere of the developed consciousness (...) Phantasy plays a most decisive function in the total mental structure: it links the deepest layers of the unconscious with the highest products of consciousness (art), the dream with the reality; it preserves the archetypes of the genus, the perpetual but repressed ideas of the collective and individual memory, the tabooed images of freedom (...) imagination preserves the 'memory' of the subhistorical past when the life of the individual was the life of the genus, the image of the immediate unity between the universal and the particular under the rule of the pleasure principle (...) phantasy has a truth value of its own, which corresponds to an experience of its own - namely, the surmounting of the antagonistic human reality. Imagination envisions the reconciliation of the individual with the whole, of desire with realization, of happiness with reason" [37; pp.140-143].

<sup>39</sup>Schoolman to a certain extent perceives Marcuse's criterion of truth: "In fact, since Marcuse's theory of historicity maintains that all meaning, including standard of truth and validity, are formed within a historical, social context, his theory excludes a transcendental foundation for criteria of rationality. By maintaining that conceptual meaning, in particular, criteria of rationality, that is concepts of truth and falsity or of right and wrong, is always defined within a social context, Marcuse has explicitly followed not only Hegel (...) and Marx but Wilhelm Dilthey as well" [35; p.31].

<sup>40</sup>For Marcuse's lifelong commitment to Marxist project see [2].

<sup>41</sup>This is somehow present in MacIntyre and Vivas as well. MacIntyre utterly improperly and unfoundedly proposes the argument that Marcuse equated USA with Hitler's Germany: "In his early writings of 1934 Marcuse argued that liberalism had as its natural successor totalitarianism. In 1960 he takes the prevailing social order of the advanced countries to embody just such totalitarianism. He is thus prepared to characterize in the same terms Hitler's Germany and the United States of Kennedy, Johnson and Nixon – or at the least he is committed to hold that there are strong and growing tendencies in the United States which may be characterized in key respects as resembling Nazism (...) In assimilating Nazi Germany to such societies as those of North America and of Britain today Marcuse can only assist in obscuring the small but genuine threat from the neo-Fascist right that does exist in those societies" [34; pp.67-68].

Vivas of course follows MacIntyre: "Marcuse also suggests that our society is totalitarian in the sense that Nazi Germany was and that Russia and China are" [33; p.48].

MacIntyre is evidently unfamiliar with Marcuse early writings and the essay to which MacIntyre is referring is *The struggle against liberalism in the totalitarian view of the state*. However, MacIntyre (and Vivas) had not read carefully and thoroughly this essay. It should also be said that in the later works to which MacIntyre is referring, Marcuse never compared the US with Hitler's Germany. Marcuse clearly speaks about key differences of the two: "This is not a fascist regime by any means. The courts still uphold the freedom of

the press; ‘underground’ papers are still being sold openly, and the media leave room for continual and strong criticism of the government and its policies. To be sure, freedom of expression hardly exists for the blacks, and is effectively limited even for the whites. But civil rights are still there, and their existence is not disproved by the (correct) argument that the system can still ‘afford’ this kind of protest (...) There is little need to stress the facts that in the United States the situation is different from Weimar Germany, that there is no strong Communist Party, that there are no paramilitary mass organizations, that there is no total economic crisis, no lack of ‘living space,’ no charismatic leaders, that the Constitution and government set up in its name are well functioning, and so on. History does not repeat itself exactly, and a higher stage of capitalist development in the United States would call for a higher stage of fascism” [39; pp.24-25].

<sup>42</sup>Farr holds these Marcuse’s notions to be crucial for development of more democratic societies: “The notion of a new sensibility is one of Marcuse’s most radical and important insights. It is my position that without the development of a new sensibility full democracy is not possible (...) A pure democracy is one that has purged itself of the need from domination whether that domination is based on class, race, sex or gender, sexual orientation or nationalism. Such a democracy tends towards humanism wherein the dignity and the right to the necessary resources for self-determination and self-development of all human beings is affirmed. Such a democracy is put into action y more than an appeal to the so-called principles of democracy (...) Marcuse’s notion of the new sensibility introduces a care perspective. The care perspective moves us beyond the mere applications of principles. The care perspective invoked by Marcuse’s new sensibility must be made universal via humanism, that is, the cultivation of care toward all humanity” [3; pp.115-116].

<sup>43</sup>Kellner correctly asserts that in contrast to the ideals philosophical models of subjectivity: “... Marcuse posits a bodily, erotic, gendered, social, and aestheticized subjectivity that overcomes mind-body dualism, avoids idealist and rationalist essentialism, and is constructed in a specific social milieu. Moreover, Marcusean subjectivity is challenged to reconstruct itself and emancipate itself from limited and oppressive forms and to pursue the project of cultivating a new sensibility” [40; pp.3-4].

<sup>44</sup>e.g. Soviet realism or commercialization and mass production of art in the advanced technological civilization.

<sup>45</sup>This is evident in Whitfield’s statement: “For example, *Eros and Civilization* envisions technology as a catalyst of emancipation, freeing humanity from drudgery and permitting a polymorphous sexuality to pervade utopia. The latter book [*One-dimensional Man*] repudiates technocratic bureaucracy, however, and condemns the exploitation of nature that scientific progress is supposed to achieve” [42; p.106].

<sup>46</sup>To this confusion adds Schoolman’s misconception about Weber’s critical influence on Marcuse’s dealing with technology. It should be said that it was Heidegger’s essay *Question Concerning Technology* that influenced Marcuse.

<sup>47</sup>Perhaps best explanation on this subject offers Mattick: The capital-labour relationship determines the unfolding of technological development as the accumulation of capital. Only within the frame of capital formation do science and technology expand the capacities of social production by increasing the productivity of labour. Under the social relations of capital production the given potentialities of socialized production cannot be fully realized, since their realization would destroy existing capitalist production relations. At a certain point in its development, capital becomes a hindrance to a further unfolding of the social forces of production, and, from the point of view of production, changes from a progressive into a regressive force. Only destruction of the capitalist system can now assure continued progressive social development. Marcuse himself points out that in Marxian theory ‘the social mode of production, not technics, is the basic historical factor.’ (...) For Marcuse, the

present technology is specific to, but not limited by, capitalism. It offers a way out for capitalism and is therefore the most important obstacle to its abolition. For Marx, too, science and technology are specific to capitalism, but only in the sense that their direction and development find their determination and limitations in capitalist relations of production. Should these relations be abolished, science and technology could take on an unhampered and different course, in accordance with the conscious and rational decisions of fully-socialized man. For Marx, it is neither science nor technology which constitutes a system of domination, but it is the domination of labour by capital which – with everything else – turns science and technology into instrumentalities of exploitation and class rule. In Marcuse's view, however, it is no longer capitalism which determines the state and nature of technology; it is technology which determines the state and nature of capitalism (...) Yet, all that capitalism can accomplish in this way, even in Marcuse's view, is its own maintenance by keeping technological progress within the boundaries of class domination. But as this technology finds – by and large – the support of all layers of society by satisfying their material needs, it can assure its domination over, and its growth within, class society" [45; pp.9-10].

<sup>48</sup>i.e. One can notice that *One-Dimensional Man* is written under the influence of Hegelian and Marxian categories and dialectics. As Kellner points out: "In retrospect, *One-Dimensional Man* articulates precisely the Hegelian-Marxian philosophical project that Marcuse began developing in the 1930s in his work with the Frankfurt School" [46; p.xviii]. Another example: in *Eros and Civilization* in the part where Marcuse discusses the possibility of eros' victory over thanatos, one can notice that Marcuse is closely following and building on Heidegger's being-toward death.

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## CROATIAN HIGHLY CITED PAPERS

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### ABSTRACT

Highly cited papers are among the most commonly used indicators for measuring scientific excellence. The primary purpose of this study is to determine characteristics of highly cited papers authored or co-authored by Croatian researchers and to identify patterns of their national and cross-national collaboration. The Clarivate Analytics Web of Science Core Collection was used for collecting data. Data were filtered for the highly cited papers published in the 2008-2018 period. Half of 428 identified highly cited papers were published in only 18 journals. The distribution across subject areas showed a strong domination of the fields of physics and clinical medicine. The median number of authors per average paper was 30,5, while the same value in the case of Croatian authors was 2. Only 4% of the analysed papers were authored by Croatian researchers only. The national inter-institutional collaboration was marginal and mainly visible through joined collaboration with foreign institutions. European institutions are most frequently found among the authors' addresses. For a small country on the scientific periphery, international cooperation is a prerequisite not only for the publication of highly cited papers but also for acquiring additional research experience in mainstream scientific teams.

### KEY WORDS

highly cited papers, scientifically peripheral countries

### CLASSIFICATION

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## **INTRODUCTION**

Science is a gift economy [1] which relies on intangible rewards like recognized contributions to knowledge and impact on ideas of other scientists. Scholarly publications allow their readers to identify this background information. A citation is basically an acknowledgment indicating which publication influenced someone's research and published work. Bornmann and Daniel [2] argue that citations are not only an indication of the (superficial) relevance of research but are also an indicator for the relevance of an investigation or a study for scientific activity in a research field.

Despite a number of controversial technical questions [3], the citation count is nowadays a standard method of research evaluation and comparison of research performance between individual researchers, departments, and research institutions [4]. The method is also used for the country and/or cross-country evaluation of research performance.

According to Aksnes [5] a large majority of scientific papers are never or seldom cited in subsequent scientific literature. However, some papers do receive an extremely large number of citations. Zitt et al. [6] emphasize that highly cited articles are among the most commonly used indicators for measuring "excellence". Their importance in research assessment has been recently growing as they became a component in some global university and institution rankings, such as the Leiden or Shanghai rankings. Aksnes and Sivertsen [7] found that the average citation by countries in different fields of science depended on a few highly cited papers to a large extent.

The term "highly cited paper" may be defined in a number of ways [8-10]. Many recently published studies used Clarivate Analytics Essential Science Indicators (ESI) according to which highly cited papers (HCPs) are papers that received enough citations to be placed in the top 1% papers in the academic field of each 22 subject areas based on a highly cited threshold for the field and publication year [11].

The main characteristics of HCPs were determined by Aksnes [5], and among them are a large number of affiliated authors, international collaboration, publishing in high-impact journals and over-representation of review articles. These findings were confirmed in the analysis of the research impact in countries with high scientific productivity as well as in small scientific communities. In their comprehensive assessment of Chinese HCPs, Fu et al. [12] confirmed international collaboration and multiple authorship of HCPs as well as a high share of articles belonging to hard sciences. Pisyakov and Shukshina [13] found that about 92% of Russian highly cited papers involved international collaboration, which is a several times higher share in comparison with the share in the overall Russian output (35%). Elango and Ho [14] analysed HCPs from India and they also identified patterns of international collaboration and high-impact journals in the HCP production and publishing.

The share and characteristics of HCPs in the overall production of scholarly articles in small or/and peripheral scientific communities have not been sufficiently analysed. However, the studies of Malaysian [15] and Slovenian HCPs [16] showed that these papers generally share the same characteristics: they are internationally collaborative, multiauthored, published in highly influential journals and belong to hard science disciplines. Goldfinch et al. [17] stated that scientists on the periphery and their institutions "should look to tie their research as strongly as they can to the international community if they wish to increase the impact of their research and the benefits this might entail".

Croatia is a small scientific community with 0,86% gross domestic expenditure on research and development (GERD) in 2016. The country joined the European Union in 2013 and it increased both the funding from the European resources and the level of research collaboration.

The EU Research and Innovation Observatory (RIO) monitors and analyses the research and innovation development in the EU countries producing RIO Country Reports every year [18]. One of the indicators employed is the highly cited publication indicator defined as a country's number of scientific publications among the top 10% most cited publications in fractional counting. The analysis is based on the Web of Science data with the citation window of publication year plus two years. Looking at the 2015 data for all 28 EU countries, Bulgaria, Lithuania, and Croatia have the lowest shares in the top 10% most cited publications in the total scientific publication of the country.

The primary purpose of this study is to determine characteristics of Croatian HCPs as they are defined by the Clarivate Analytics ESI and to identify the most important national institutions producing HCPs as well as patterns of their national and cross-national collaboration. At the same time, the field distribution of HCPs will be identified as well as their JCR quartile distribution. The second goal of the study is to examine whether the Croatian HCP sample confirms the characteristics of previous research and displays some features that might be typical of small and peripheral scientific communities.

## MATERIALS AND METHODS

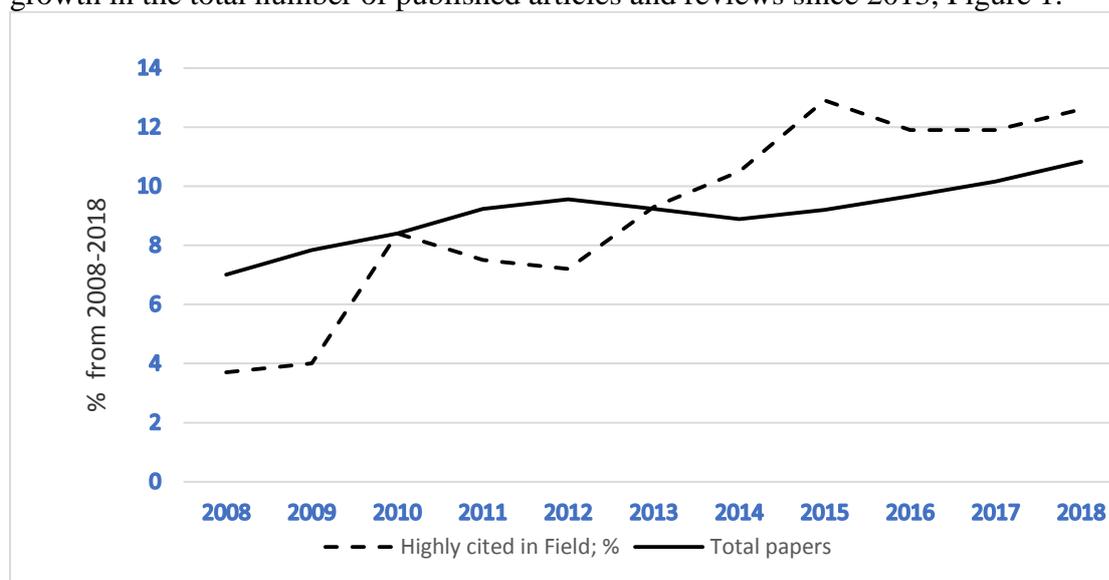
The web interface of Clarivate Analytics Web of Science Core Collection (WoS CC) was used to collect data. Databases were first searched by the terms Croatia or Hrvatska in the address field. The result was then refined by applying the "highly cited in field" filter.

The highly cited papers included in our study were published in the 2008-2018 period because a 10-year interval is the cumulative time period used for the ESI to calculate which papers are highly cited. All 22 subject areas were included in the analysis.

The data were collected in April 2019 and were partially analysed by using the InCite tools. The crosstab analysis was done by using the SPSS package.

## RESULTS AND DISCUSSION

The search of the WoS CC resulted in the identification of 428 HCPs with at least one Croatian address. This is 0,008 % of a total of 52 077 WoS CC indexed documents of the article and review types in the 11 years. The growth in the number of HCPs has exceeded the growth in the total number of published articles and reviews since 2013, Figure 1.



**Figure 1.** Yearly distribution of total number of papers (articles and reviews) and number of HCPs.

## TYPE OF PAPERS AND THEIR CITATION RATE

Our sample consisted only of articles (84,6%) and reviews (15,4%). The shares do not fully correspond to the total number of published documents of these types (93,8% vs 6,2%) in the analysed period. The share of the highly cited review articles is 2,5 times higher. This confirmed Aksnes's findings [5] on the over-representation of review articles compared to the country's average. The citation share of the review articles in the total citation score is 13,3%, Table 1.

**Table 1.** Type of HCPs and their citation rate.

	No. of documents	%	No. of citations	%
Articles	362	84,6	93 108	86,7
Reviews	66	15,4	14 298	13,3
Total	428	100,0	107 406	100,0

The WoS definition of the article as a document type primarily relates to the "reports of research on original works". However, it should be noted that these databases classify also recommendations, consensus papers, position papers and guidelines into the article category although such papers present only statements aimed at supporting particular decision-making [19]. Their citation rate is usually very high and their impact on the total citation score may be significant. In our sample we found 32 papers (9%) of that type and all of them were classified as articles. Their total citation score was 10,117, almost 11% of the total citation score for all HCPs classified as articles.

## SOURCE TITLES

The HCPs from our sample were published in 178 different journals; half of them were published in only 18 journals (Table 2). In the group of the top 18 journals, six journals

**Table 2.** Journals with most HCPs published.

Journal Titles	Frequency	Percent	Cumulative Percent
Physics Letters B	34	7,9	7,9
Physical Review Letters	26	6,1	14,0
Nature	22	5,1	19,1
Nature Genetics	16	3,7	22,9
Lancet	14	3,3	26,1
Food Chemistry	12	2,8	28,9
European Physical Journal C	11	2,6	31,5
Journal of Instrumentation	11	2,6	34,1
Journal of High Energy Physics	9	2,1	36,2
Proceedings of The National Academy of Sciences of The United States of America	9	2,1	38,3
Physical Review C	8	1,9	40,1
European Heart Journal	7	1,6	41,8
Science	7	1,6	43,4
Journal of Crohns & Colitis	6	1,4	44,8
Journal of Pediatric Gastroenterology and Nutrition	6	1,4	46,2
Lancet Oncology	6	1,4	47,6
New England Journal of Medicine	5	1,2	48,8
Physical Review D	5	1,2	50,0

belong to the field of physics and six to the field of clinical medicine, while four journals belong to the multidisciplinary category.

Aksnes [5] emphasised that “highly cited papers tend to be published in high impact journals”. The JCR quartile distribution showed that 86,4% of journals were ranked as Q1 in their subject categories, Table 3. This percentage is higher or similar to the results of other studies [15, 16].

**Table 3.** Journals’ publishing year JCR Qs.

<b>Publishing year Q</b>	<b>Frequency</b>	<b>Percent</b>
None	5	1,2
Q1	370	86,4
Q2	42	9,8
Q3	10	2,3
Q4	1	0,2
<b>Total</b>	<b>428</b>	<b>100,0</b>

## SUBJECT AREAS

The distribution of the Croatian HCPs across subject areas (Table 4) showed a strong domination of the fields of physics and clinical medicine. A Croatian affiliation was found in 113 analysed documents (26,4%) in the field of physics and in 95 analysed documents in the field of clinical medicine (22,2%). The area of molecular biology and genetics is the third top field (10,1%). A similar pattern can be found in other studies too [13, 16].

**Table 4.** HCPs distribution across 20 ESI subject areas.

<b>Highly cited field</b>	<b>Frequency</b>	<b>Percent</b>	<b>Cumulative Percent</b>
Physics	113	26,40	26,40
Clinical Medicine	95	22,20	48,60
Molecular biology & genetics	43	10,05	58,64
Chemistry	19	4,44	63,08
Engineering	19	4,44	67,52
Social Sciences	15	3,50	71,03
Agricultural sciences	25	3,50	74,53
Biology & Biochemistry	15	3,50	78,04
Space science	13	3,04	81,07
Neuroscience & Behavior	12	2,80	83,88
Plant & Animal Science	12	2,80	86,68
Environment/Ecology	11	2,57	89,25
Geosciences	11	2,57	91,82
Materials Science	6	1,40	95,56
Immunology	6	1,40	96,96
Psychiatry/Psychology	4	0,93	97,66
Multidisciplinary	3	0,70	98,36
Pharmacology & Toxicology	3	0,70	99,06
Mathematics	2	0,47	99,53
Microbiology	1	0,23	100,00
<b>Total</b>	<b>428</b>	<b>100,00</b>	

Previous studies of the Croatian scientific productivity and impact also showed that physics and clinical medicine have been leading research areas [20; pp.114-116, 21], and that their share was about 50%. Croatian authors in both preclinical and clinical medicine have traditionally a prominent international output. If the HCPs in the fields of clinical medicine, immunology, neuroscience and psychiatry are combined into one broad category of biomedicine, this category takes the first place.

The HCPs are mainly present in “hard sciences”. With the exception of 15 papers (3%) classified into the subject area of social sciences, all other papers belong to “hard” scientific fields. The HCPs classified into the social sciences area are also borderline papers of anthropological, epidemiological or public health content orientation.

Two ESI subject areas have not been represented in our sample. These are computer science and economics and business areas. These two areas generally have a lower number of HCPs, and that may be attributed to differences in citation patterns across scientific fields [22, 23].

## AUTHORS AND THEIR AFFILIATIONS

Multi-authorship is one of the most important characteristics of HCPs [5]. We found the median value of 30,5 authors per average paper. Even 73 papers (17%) were authored by more than 1000 researchers. The maximum number of authors is 5 153. Two single-author papers belong to the fields of mathematics and agricultural sciences.

The papers from the field of physics have the highest average number of authors per paper, i.e. 1378,48.

The median number of Croatian authors is 2 per paper. Their number varies in range from 1 to 22. Almost 50% of papers has one Croatian author in the byline. The highest average number of Croatian authors per paper is 8,07, found in the field of physics, Table 5.

**Table 5.** Number of HCPs authors across the ESI subject areas.

ESI subject area	No. of HCPs	Total no. of authors	Average no. of authors per paper	No. of Croatian authors	Average no. of Croatian authors per paper
Agricultural sciences	25	184	7,36	109	4,36
Biology & Biochemistry	15	1233	82,20	44	2,93
Chemistry	19	24 701	1300,05	140	7,37
Clinical Medicine	95	10 783	113,50	202	2,13
Engineering	19	93	4,90	30	1,58
Environment/Ecology	11	257	23,36	23	2,09
Geosciences	11	360	32,72	18	1,64
Immunology	6	390	65,00	14	2,33
Materials science	6	55	9,17	6	1,00
Mathematics	2	3	1,50	3	1,50
Microbiology	1	2	2,00	1	1,00
Molecular biology & genetics	43	8 983	208,90	102	2,37
Multidisciplinary	3	216	72,00	5	1,67
Neuroscience & Behavior	12	304	25,33	20	1,67
Pharmacology & Toxicology	3	17	5,67	3	1,00
Physics	113	155 768	1378,48	912	8,07
Plant & Animal Science	12	613	51,08	31	2,58
Psychiatry/Psychology	4	159	39,75	5	1,25
Social Sciences	15	1096	73,07	30	2,00
Space science	13	2 514	193,38	34	2,62

We found 72 papers (16,8%) with a Croatian researcher as the first or corresponding author. This is significantly less than what findings of other studies show [15, 16].

According to our results, there are three Croatian centers of scientific excellence. The majority of Croatian researchers who authored/co-authored the HCPs have been affiliated to the University of Zagreb, University of Split or the Ruđer Bošković Institute, Table 6.

## INSTITUTIONAL COLLABORATION

According to many former studies, HCPs are characterised by strong international collaboration. The number of institutions participating in the production of HCPs in our sample varies from 1 to 1164 with a median of 25 per average paper. Only 17 papers (4,0%) in our sample were authored by Croatian researchers only. The national inter-institutional collaboration is marginal (Table 7) and it is mainly visible in the joined collaboration with foreign institutions. This supports one of the main characteristics of small scientific communities and scientifically peripheral countries, the so called “intellectual island effect” [24], primarily reflected in an incapacity of effective local research collaboration.

Discussing the reasons for the growing level of the international scientific collaboration, Wagner and Leydersdorff [25] mentioned an increasing specialisation within scientific fields, sharing centrally located facilities (e.g. CERN), and primarily the network organization of international collaboration. They say that “the network of international collaboration is highly dynamic, quickly changing, and very influential” and that “it feeds back into the national, regional, and local levels, influencing the organization of science”. Therefore, researchers on the periphery tend to tie strongly their research to internationally renowned institutions which enables them to gain experience and discuss their ideas.

**Table 6.** Croatian institutions participating in production of HCPs.

Croatian institutions	Web of Science HCPs	Times cited	HCPs in Q1 journals
University of Zagreb	171	39 206	122
University of Split	153	49 616	120
Ruđer Bošković Institute	117	30 434	93
University of Rijeka	45	9 469	30
University of JJ Strossmayer Osijek	9	839	7
Institute for Anthropological Research Zagreb	5	801	3
Croatian Academy of Sciences & Arts	4	1732	3
Croatian Forest Research Institute	3	124	2
Institute for Medical Research & Occupational Health	3	297	1
Institute of Physics Zagreb	3	682	3
Croatian Institute of Oceanography & Fisheries	2	29	1
Croatian Veterinary Institute Zagreb	2	42	1
University of Zadar	2	1764	2
University of Dubrovnik	1	70	1

**Table 7.** National collaboration.

Institution	HCPc	Times cited
University of Zagreb – University of Split	19	8 584
University of Zagreb – Ruđer Bošković Institute	7	1004
Ruđer Bošković Institute – University of Split	77	20 449

**Table 8.** International collaboration resulting in  $\geq 100$  HCPs.

Collaborative institution	Web of Science HCPs	Times cited
Helmholtz Association, Helmholtz Assoc MDC, Max Delbruck Ctr Mol Med, Mol Epidemiol Res Grp, Berlin, Germany	150	43 913
Univ California System	147	48 758
Universite Paris-Est Marne-la-Vallee, Centre National de la Recherche Scientifique (CNRS), National Institute for Mathematical Sciences	135	38 082
Universite Paris Saclay (ComUE), Paris Saclay Univ, L2S, 3 Rue Joliot Curie, Gif Sur Yvette, France	127	36 515
Univ Helsinki	126	37 060
Imperial College London	124	36 391
Massachusetts Institute of Technology (MIT)	118	38 643
Univ Padua	111	29 628
CEA, Inst Crustal Dynam, Beijing 100085, Peoples R China	110	30 094
United States Department of Energy (DOE)	109	27 355
Boston University	108	34 101
Univ Athens	108	27 842
Ohio State University	106	28 178
Universite de Strasbourg	102	27 963
Univ Turin	102	28 411
Univ Cantabria, Consejo Superior de Investigaciones Cientificas (CSIC), E-39005 Santander, Spain.	101	26 148
Sapienza University Rome	101	26 335
Chinese Academy of Sciences	100	27 074

European scientific institutions are most frequently found among the authors' addresses of the HCPs making our sample, Table 8. This is possibly so because of the EU extensive programmes for research and innovations in which Croatia has been participating more actively in the last five years.

## RESEARCH FUNDING

According to the data available in the WoS CC databases, 274 funding agencies participated in the research projects which resulted in HCPs authored or co-authored by Croatian scientists. The projects which resulted in  $\geq 50$  HCPs were financed by 31 agencies with the US National Science Foundation and German Research Foundation (DFG) leading the list, Table 9. The Croatian Ministry of Science and Education, the main Croatian research funding body, participated in funding projects which resulted in the production of 53 HCPs (12%). As already mentioned, according to the Eurostat data for 2017 [26], the Croatian R&D expenditure is among the lowest in the European Union (0,86% of GDP).

## TOP 10 HCPs

The 10 most frequently cited HCPs were published in journals classified by the ESI in five subject areas. According to the overall results, physics was the most frequently cited field with 26,4% of HCPs (Table 4). However, there was only one paper dealing with a topic belonging to physics among the most frequently cited ten HCPs, the first paper on the list, with

**Table 9.** Source of funds.

<b>Funding Agency</b>	<b>Rank</b>	<b>Web of Science HCPs</b>	<b>Times cited</b>
US National Science Foundation (NSF)	1	100	25 589
German Research Foundation (DFG)	2	97	20 564
German Federal Ministry of Education & Research (BMBF)	3	90	18 000
National Natural Science Foundation of China	4	89	20 599
United States Department of Energy (DOE)	5	81	20 358
Brazilian National Council for Scientific and Technological Development (CNPq)	6	81	18 292
European Union (EU)	7	80	17 833
Istituto Nazionale di Fisica Nucleare	8	79	18 299
UK Science & Technology Facilities Council (STFC)	9	78	18 192
Fundacao de Amparo a Pesquisa do Estado de Sao Paulo (FAPESP)	10	74	17 617
Academy of Finland	11	74	15 452
Mexican Consejo Nacional de Ciencia y Tecnologia (CONACyT)	12	72	17 150
Department of Atomic Energy (DAE)	13	72	17 143
Greek Ministry of Development-GSRT	14	71	16 162
Chinese Academy of Sciences	15	67	14 958
European Research Council (ERC)	16	64	14 797
Centre National de la Recherche Scientifique (CNRS)	17	64	14 733
CAPES, Tecnologia e Inovacion Colciencias (Brasil)	18	63	14 584
Portuguese Foundation for Science and Technology	19	62	15 022
Departamento Administrativo de Ciencia	20	62	14 580
Science Foundation Ireland	21	61	14 452
Scientific & Technological Research Council of Turkey (TUBITAK)	22	60	14 233
Fundacao Carlos Chagas Filho de Amparo a Pesquisa do Estado do Rio de Janeiro (FAPERJ)	23	59	14 028
Russian Academy of Sciences	24	59	9 253
Russian Foundation for Basic Research	25	58	13 198
FWO – Research Foundation Flanders	26	57	13 385
Turkish Enerji ve Tabii Kaynaklar Bakanligi	27	55	13 193
Ministry of Science and Education, Republic of Croatia	28	53	13 051
Fonds de la Recherche Scientifique (FNRS)	29	52	11 963
Alexander von Humboldt Foundation	30	51	12 689
French Atomic Energy Commission	31	50	12 968

2,3 times more citations than the next paper, Table 10. Among 228 participating institutions and 2 891 authors, there were two Croatian institutions (University of Split and Ruder Bošković Institute) with 12 affiliated scientists.

Seven papers from the list were published in the fields of molecular biology and genetics (4) and clinical medicine (3). All three clinical medicine papers belong to the group of guidelines and systematic reviews and they are regularly very influential and highly cited.

On the list of top 10 papers there is a paper authored exclusively by Croatian researchers and produced by the Croatian leading research institution. This paper gives a description of a free accessible web application for summarizing and visualizing the gene ontology categories. Methods papers, particularly those focused on computational methods, are generally among the most frequently cited papers [27, 28].

Nine out of ten papers on the list were published between 2010 and 2015. Some authors argue that the papers published earlier have an advantage over the papers published later as more citations can be accumulated [29]. The time factor obviously does not have a critical influence on the citation ranking of the analysed HCPs.

**Table 10.** Most frequently cited HCPs.

Total no. of authors	No. of Croatian authors	Croatian first or corresponding author	Croatian affiliations	Citations	ESI subject area	Journal	Document type	Croatian funding	Published
2891	12	No	University of Split; Ruđer Bošković Institute	5099	Physics	Physics Letters B	Article	Yes	2012
1268	1	No	University of Split	2177	Molecular biology & genetics	Autophagy	Review	No	2012
18	1	Yes	University of Zagreb	1851	Clinical medicine	European Heart Journal	Article	No	2011
2834	22	No	University of Zagreb; University of Zadar; 9 hospitals	1733	Clinical medicine	New England Journal of Medicine	Article	No	2013
375	5	No	University of Zagreb; University of Split	1650	Molecular biology & genetics	Nature Genetics	Article	Yes	2010
3100	9	No	Ruđer Bošković Institute	1650	Chemistry	Journal of Instrumentation	Review	No	2008
56	1	No	Croatian Academy of Sciences & Arts	1565	Molecular biology & genetics	Science	Article	No	2010
95	1	No	University of Zagreb	1337	Molecular biology & genetics	Nature	Article	No	2015
4	3	Yes	Ruđer Bošković Institute	1325	Biology & Biochemistry	PLOS ONE	Article	Yes	2011
21	1	No	University of Split	1241	Clinical Medicine	Lancet	Article	No	2010

## CONCLUSIONS

The main characteristics of the HCPs authored/co-authored by Croatian researchers are similar to those described in the previous studies. The Croatian HCPs are multi-authored, internationally collaborative, published predominantly in the field of hard sciences and in highly cited journals. Almost half of the HCPs belong to the fields of physics and clinical medicine, and half are published in 18 journals, all ranked as JCR Q1. European scientific institutions are most frequently found among the authors' affiliations and the median value of authors per average HCP is 30,5.

The HCPs characteristics that can be attributed to small and/or scientifically peripheral countries relate to the low participation of local funds, a lack of local research co-operation and few local authors being the first or corresponding authors.

Not more than 4,0% of all analysed HCPs were authored by Croatian authors exclusively, and 16,8% had a Croatian researcher as the first or corresponding author.

The Croatian Ministry of Science and Education participated in funding projects which resulted in the production of 12% of the analysed HCPs.

The majority of the Croatian researchers who authored/co-authored the HCPs have been affiliated to the University of Zagreb, the University of Split or the Ruđer Bošković Institute.

The national inter-institutional collaboration has been minimal and mainly visible in the joined collaboration with foreign institutions.

Discussing the 63% of the Norwegian highly cited papers involving international collaboration, Aksnes said that the concept of "Norwegian papers" appears rather problematic [5]. It seems that this could be said for our results as well. However, cross-border links in science, with resources being diffused in international networks, were considered to be the extension of national systems finding opportunities to complement each others' capabilities [30].

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## CORRIGENDUM

**Palić, I.; Banić, F. and Matić, L.: The Analysis of the Impact of Depreciation on External Debt in Long-Run: Evidence from Croatia. *Interdisciplinary Description of Complex Systems* 16(1), 186-193, 2018. <http://dx.doi.org/10.7906/indecs.16.1.15>.**

DOI: 10.7906/indecs.17.3.21

Corrigendum

Correct form of the first sentence of the subsection *Data and Methods* (p.189) is as follows:

Monthly data from June 2009 to February 2017 on both gross external debt and nominal effective exchange rate indices are used in empirical analysis.



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