

# INTERDISCIPLINARY DESCRIPTION OF COMPLEX SYSTEMS

**Scientific Journal**

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## **INTERDISCIPLINARY DESCRIPTION OF COMPLEX SYSTEMS**

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## **EDITORIAL: NEW TRENDS IN ROBOTICS**

Dear readers,

robotics is a particularly complex and heterogeneous discipline. Therefore, standard approaches to assess scientific research are not sufficient. With progress in microprocessor, sensor, actuator and cloud computing technology, as well as permanent progress of scientific knowledge in the field of Robotics, new trends in development of services, cloud robots and internet of things appear and boost things strongly forward. This challenge is to extend systems engineering methods to deal with open-ended and frequently changing real-world environments.

This thematic issue also concerns with new trends in intelligent robots in light of involving new technologies and use of scientific innovations. In particular, the issue regards to innovations and improvements in design, development and implementation of cloud robotics, wheeled mobile and flying robots.

The aim of the thematic issue is to offer researchers an opportunity to extend the existing scientific relationship all over the world in the field of intelligent robots including Cloud Robotics, Flying Robots, Internet of Things, Wheeled Mobile Robots, Fuzzy Systems and Control Technics.

Let me hope that researchers working in various institutions will find common research areas at the thematic issue so that they can co-operate on international projects. The majority of these works focus on Robotics that can be successfully implemented in various areas of developing industries all over the world. Good cooperation between industrial and academic partners can further amplify innovations.

Cordially,

Szeged, 29<sup>th</sup> January 2015

Guest editor

Prof. Gyula Mester



# CLOUD ROBOTICS MODEL

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Regular article

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## ABSTRACT

Cloud Robotics was born from the merger of service robotics and cloud technologies. It allows robots to benefit from the powerful computational, storage, and communications resources of modern data centres. Cloud robotics allows robots to take advantage of the rapid increase in data transfer rates to offload tasks without hard real time requirements. Cloud Robotics has rapidly gained momentum with initiatives by companies such as Google, Willow Garage and Gostai as well as more than a dozen active research projects around the world. The presentation summarizes the main idea, the definition, the cloud model composed of essential characteristics, service models and deployment models, planning task execution and beyond. Finally some cloud robotics projects are discussed.

## KEY WORDS

service robotics, cloud technologies, robotics, cloud robotics, service models

## CLASSIFICATION

ACM: D.1.1.

JEL: O31

PACS: 89.70.Hj

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## WHAT IS CLOUD ROBOTICS?

Cloud Robotics (CR) was born from the merger of cloud technologies and service robotics [1], which was preceded by a change in paradigm in both domains [2]. It allows robots to benefit from the powerful computational, storage, and communications resources of modern data centres.

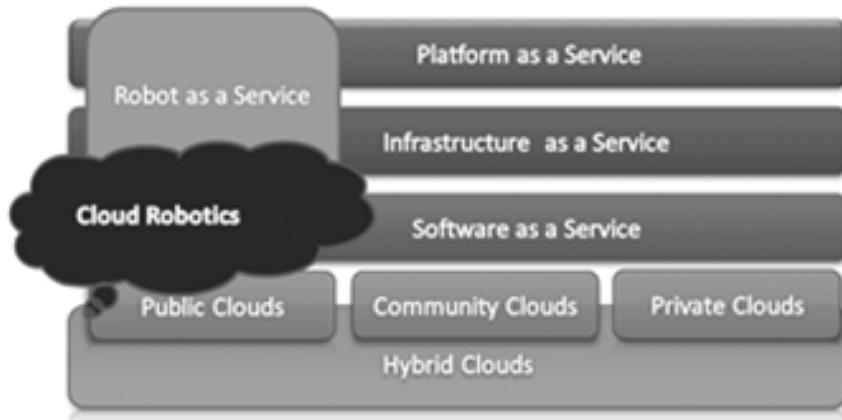
Cloud robotics allows robots to take advantage of the rapid increase in data transfer rates to offload tasks without hard real time requirements.

The term “cloud-enabled robotics” was presented by James Kuffner for the first time at the IEEE RAS Int. Conference on Humanoid Robotics in 2010. He was first to point out the potential of distributed networks combined with robotics, primarily to enhance the robot [3].

Cloud Robotics has rapidly gained momentum with initiatives by companies such as Google, Willow Garage and Gostai as well as more than a dozen active research projects around the world. The increasing number of robots with up to date knowledge will become a true helping hand for humans. In 2011, at the Google I/O developer Conference, Google and Willow Garage introduced their theory and foreseen application of Cloud Robotics [4].

Cloud Robotics is currently driving interest in both academia and industry, combines robot technology with network and Cloud-computing infrastructure that connects amount of robots, sensors, portable devices and most important a data-centre (Figure 1).

Driven by advances in mobile communication technologies, more and more robotics applications can be executed in the cloud [5].



**Figure 1.** Cloud computing service models, the concept of Robot as a Service and Cloud Robotics.

## ROBOTICS SCHOOL AND CLOUD ROBOTICS

The robotics school and cloud robotics complement each other. The increasing number of robots with up to date knowledge will become a true helping hand for humans. Cloud robotics is the use of a cloud computing to share resources and learning among robots through the internet [6]. The robotics cloud needs the robotics school to provide a standard coding system, knowledge structures and resources, and a method by which robots can be certified to serve in various fields [7, 8].

A robotics school is a collection of data pools, resources pools and service clusters for robots with advanced intelligence, it also has a knowledge coding standard together with an authentication standard for robots.

A robotics school is based on the concept of the robotics cloud; it is also the key element for building the robotics cloud. The concept of a robotics school mainly includes three aspects:

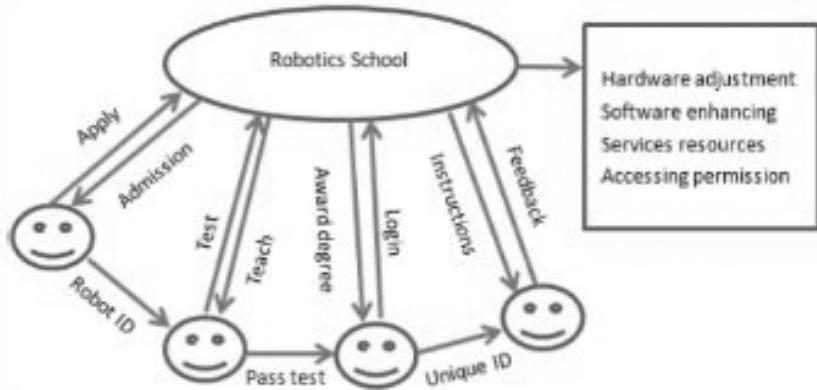
- admittance,
- teaching, learning,
- testing and graduating.

Hardware functionality must meet the hardware requirements for specific activity areas without too much encoding in software. A model of a robotics school is shown in Figure 2.

## ROBOT WEB TOOLS

Robot Web Tools is designed to enable Web developers, roboticists, and even students to start building a robot Web application quickly [9-13]. A variety of routes are available for architecting a robot web application. A common route is building web technologies on an existing robot framework.

The Robot Operating System (ROS) is one of the more popular robot middle wares to build upon. Currently available tutorials include interfaces for navigation a quadrotor (Figure 3).



**Figure 2.** A model of a robotics school.



**Figure 3.** Tutorial interface for quad-rotor navigation.

ROS (Robot Operating System) provides libraries and tools to help software developers create robot applications. It provides hardware abstraction, device drivers, libraries, visualizers, message-passing, package management, and more. ROS is licensed under an open source, BSD license [9-10].

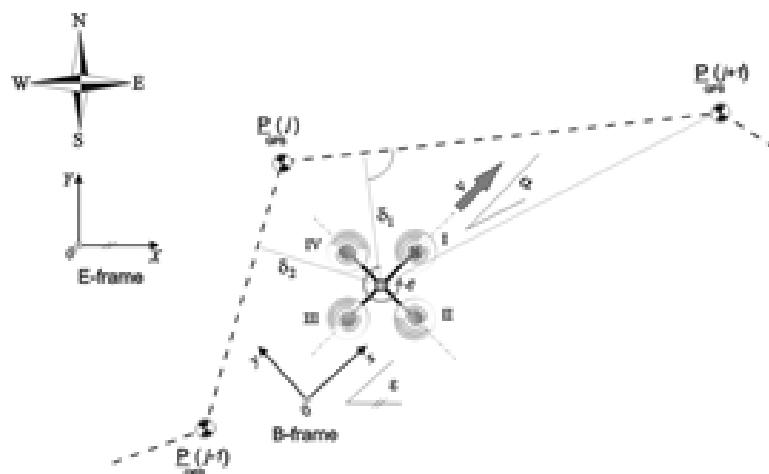
## GPS NAVIGATION OF QUAD-ROTOR

The four rotor flying robot – a quad-rotor is a four rotor helicopter. A quad-rotor helicopter is controlled by varying the rotors speed, thereby changing the lift forces. It is an under-actuated dynamic vehicle with four input forces and six outputs coordinates.

One of the advantages of using a multi-rotor helicopter is the increased payload capacity. The quad-rotors are highly maneuverable, which enables vertical take-off/landing, as well as flying into hard to reach areas [14-17]. The quad - rotor is installed a GPS sensor is used to detect the present position. Quad-rotor is requested to track the imposed trajectory between the particular points ( $j = 1, \dots, n$ ) with satisfactory precision keeping the desired attitude and height of flight. Quad-rotor checks for the current position (X and Y) by use of a GPS sensor and/or electronic compass. Trajectory of quad-rotor can be introduced by GPS coordinates, e.g.  $P_{GPS}(j)$  as shown in Figure 4.

Quad-rotor checks for the current position (X and Y) by use of a GPS sensor and/or electronic compass. Also, the altitude is measured by a barometric sensor. On-board microcontroller calculates the actual position deviation from the imposed trajectory given by successive GPS positions  $P_{GPS}(j)$ . It localizes itself with respect to the nearest trajectory segment (by calculation of the distances  $\delta_1$  or  $\delta_2$ ). Using the gyroscope, quad-rotor determines desired azimuth of flight  $\alpha$  (Figure 4) and keeps the desired direction of flight. Height of flight is also controlled to enable performance of the imposed mission (task). The corresponding Google Earth map is utilized to provide corresponding GPS coordinates of the quad-rotor trajectory as presented in Figure 5. GPS coordinates: longitude, latitude and altitude, defined in the map and given in the Figure 6, are used to calculate quad-rotor trajectory in the earth frame.

Corresponding model of the trajectory given in earth frame is presented in Figure 7.

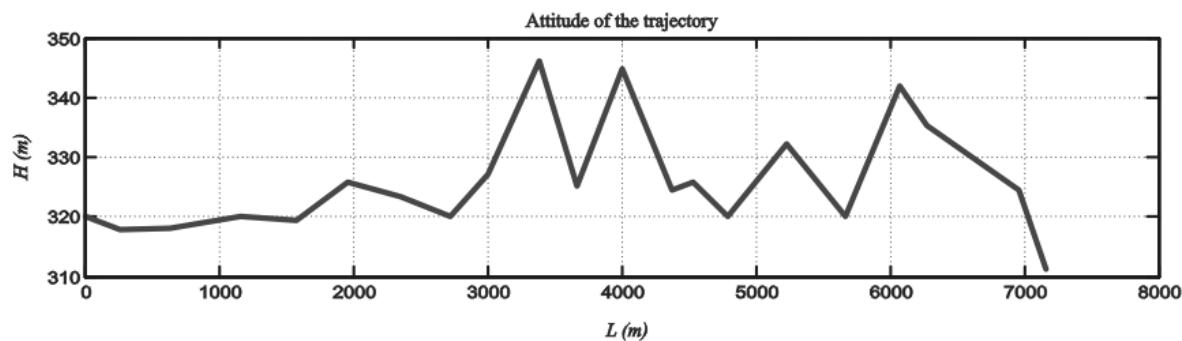


**Figure 4.** Quad-rotor localization and navigation with respect to the imposed GPS coordinates.

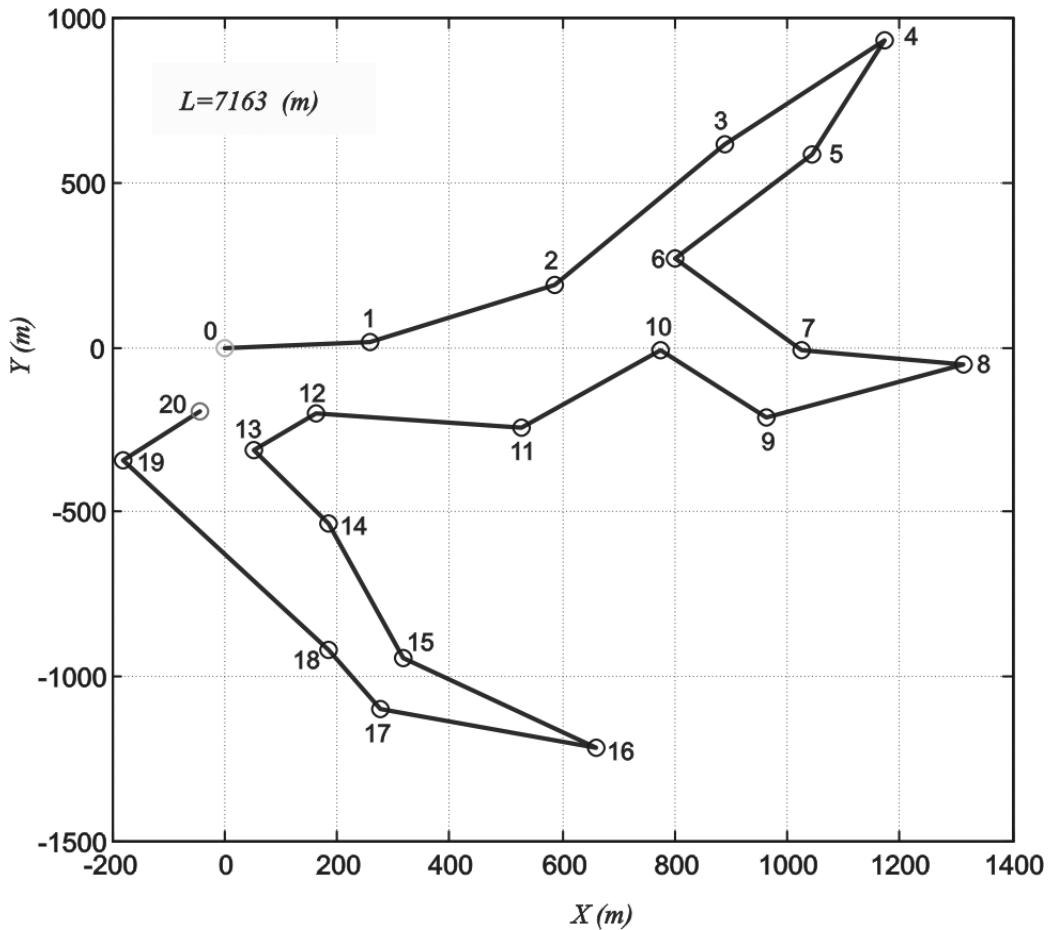


**Figure 5.** Google-Earth map of the lake used to define desired GPS trajectory of the quad-rotor flying robot.

point	LONGITUDE			LATITUDE			ATTITUDE
	degrees	minutes'	seconds"	degrees	minutes'	seconds"	
0	44	17	20.88	20	28	24.19	970
0'	44	17	20.88	20	28	24.19	970
1	44	17	21.44	20	28	36.04	963
2	44	17	27.11	20	28	50.67	964
3	44	17	40.87	20	29	4.07	970
4	44	17	51.45	20	29	17.09	968
5	44	17	39.87	20	29	11.14	987
6	44	17	29.61	20	29	0.2	980
7	44	17	20.63	20	29	10.35	970
8	44	17	19.05	20	29	23.15	991
9	44	17	14.02	20	29	7.53	1049
10	44	17	20.72	20	28	59.15	985
11	44	17	13.12	20	28	48.47	1045
12	44	17	14.54	20	28	31.86	983
13	44	17	11.05	20	28	26.98	987
14	44	17	3.83	20	28	32.98	970
15	44	16	50.71	20	28	39.13	1007
16	44	16	41.90	20	28	54.12	970
17	44	16	46.05	20	28	37.28	1036
18	44	16	53.58	20	28	31.58	1016
19	44	17	9.90	20	28	16.59	983
20	44	17	14.95	20	28	22.6	943
20'	44	17	14.95	20	28	22.6	943



**Figure 6.** GPS coordinates acquired from the Google Earth map and used for determination of the desired quad-rotor trajectory.



**Figure 7.** Multi-segment trajectory model of the quad-rotor determined in the Earth inertial frame.

## CLOUD ROBOTICS PROJECTS

Finally some Cloud Robotics projects are discussed. With the *RoboEarth* Databases and its Cloud Engine, RoboEarth provides an open-source Cloud Robotics framework that allows robots to share knowledge via a www-style database and access powerful robotic cloud services [5]. Source code and documentation are available via RoboEarth's Software Components page.

*Rosbridge* focuses on bridging communication between a robot and single ROS environment in the cloud. Available open-source via [18]. The *RosJava* library allows to run ROS on Android phones. While not strictly a cloud robotics project, it allows ROS developers to use Android devices to connect to (human) cloud services such as Google Goggles. Available open-source via [19].

The *DAvinCi* Project showed the advantages of cloud computing by parallelizing a SLAM algorithm using a Hadoop cluster [20].

The *Cloud-Based Robot Grasping* project uses Google's Object Recognition Engine to recognize and grasp common household objects. *GostaiNet* offers to execute robot behaviors such as vision and speech algorithms on compatible robots in the cloud. GostaiNet provides seamless control of any robot, using a web browser from anywhere in the world. Gostai can host the services on the GostaiNet robotics cloud [21-23].

## CONCLUSIONS

Cloud robotics allows robots to take advantage of the rapid increase in data transfer rates to offload tasks without hard real time requirements.

Cloud Robotics has rapidly gained momentum with initiatives by companies such as Google, Willow Garage, and Gostai as well as more than a dozen active research projects around the world. It allows robots to benefit from the powerful computational, storage, and communications resources of modern data centers.

The presentation summarizes the main idea, the definition. The cloud model composed of essential characteristics, service models and deployment models, planning task execution and beyond. Cloud computing can enable cheaper, lighter, smarter robots. The infrastructure exists and is rapidly evolving in terms of performance and accessibility. Finally some cloud robotics projects are discussed.

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## MODEL ROBOTIKE U OBLACIMA

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### SAŽETAK

Robotika u oblacima nastala je spajanjem uslužne robotike i tehnologija oblaka. Ona omogućava robotima korištenje pogodnosti poput znatnih resursa za računanje, pohranu i komunikaciju u modernim centrima podataka. Robotika u oblacima omogućava, nadalje, robotima korištenje znatnog porasta brzina prijenosa podataka da proslijede zadatke bez zahtjevnih vremenskih ograničenja. Robotika u oblacima dobila je znatni moment slijedom inicijativa tvrtki kao što su Google, Willow Garage i Gostai te kao što je veći broj aktivnih istraživačkih projekata po svijetu. Ovaj rad je sažetak glavne ideje, definicije, modela oblaka koji uključuje bitna svojstva te uslužnih i razvojnih modela, planiranja izvršavanja zadatka i drugoga. Nапослјетку, razmotreni su pojedini projekti robotike u oblacima.

### KLJUČNE RIJEČI

uslužna robotika, tehnologije oblaka, robotika, robotika u oblacima, uslužni modeli

# MOVING TOWARDS CLOUD SECURITY

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Regular article

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## ABSTRACT

Cloud computing hosts and delivers many different services via Internet. There are a lot of reasons why people opt for using cloud resources. Cloud development is increasing fast while a lot of related services drop behind, for example the mass awareness of cloud security. However the new generation upload videos and pictures without reason to a cloud storage, but only few know about data privacy, data management and the proprietary of stored data in the cloud. In an enterprise environment the users have to know the rule of cloud usage, however they have little knowledge about traditional IT security. It is important to measure the level of their knowledge, and evolve the training system to develop the security awareness.

The article proves the importance of suggesting new metrics and algorithms for measuring security awareness of corporate users and employees to include the requirements of emerging cloud security.

## KEY WORDS

cloud security, information technologies

## CLASSIFICATION

ACM: C.1.2., C.2.1

JEL: O39

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## INTRODUCTION

Computing is turning into a utility. Cloud is the most famous all of them, the new generation use cloud computing via their smartphones. Nowadays you can meet cloud computing everywhere. If you download an app on your smart phone, take a picture with that, storing your data – you choose cloud, because it is cheap, easy and accessible.

But what do you really know about the privacy and security? Who knows that? And who can say I know all the advantages and disadvantages of the cloud?

Unfortunately most of the cloud users do not know or do not care about it, and you can find a lot of frightening news about data integrity and confidentiality failed.

This article is focused onto what can we commence the measured results of security awareness, how can we improve it and providing a self-supporting for cloud users. All interested in the company's view, what can they do to keep their privacy and data security if they moving to the cloud, or if their employees use their mobile devices in the company's environment. How can the company create a security policy and how can they force their users to keep it up.

There is ongoing research to size up the security awareness in different companies. It includes usage of smartphones, downloading apps, using pendrives and CD-ROMs, how many different password they have, how many different business application they have to use, how often connecting to a Wi-Fi, how often sharing internet, or how often check their account on different community sites and how they can separate private and business life. On opinion is that the aforementioned features are useful, and optimize the cost, there are efficient and make everybody reachable anywhere anytime. But we need strict internet security rules, we need education to understand what can happen with us in cyberspace. It is possible to use these options – but there are a lot of situation what we need to handle using cloud computing.

## CLOUD AND ENTERPRISE IT

IT is not a typical department. IT is an enterprise-shared service that is critical to the minute-to-minute functioning of the entire organization. The availability, the confidentiality and the integrity is the most important services and IT has to provide all of them to their customers. Enterprises have invested a lot in technology, hoping to improve their execution capability, drive productivity, improve profitability and attain sustained competitive advantage. Some have been more successful than others in getting the expected returns from their technology investments but few, if any, have been able to realize the full potential of their investments. In fact, with time many enterprise IT organizations have grown in complexity as well as in size and are proving to become quite unmanageable – a drain on their business margin structures and some are even viewed as inhibitors for supporting the ever changing needs of business.

Using enterprise cloud services the companies expect, that the availability, integrity and confidentiality are provided on a higher level and they can reduce the costs at the same time. Customers want particular concrete SLA-s to provide their paid services and their properties. CIOs have to answer several questions, for example which applications will be migrated to the cloud, which could give more savings, how can make a strategy to use cloud computing as part of the IT services mix. Generally, the level of computer security, data privacy practices and the expertise of major cloud service providers are likely to be greater than those provided by an in-house IT staff and systems. This makes the security concern less salient. Nevertheless, before moving data and applications to a cloud it is important to ensure the cloud provider has strong security and privacy policies in place.

Cloud provides significant opportunities for businesses of all size. Scaling is essential function of cloud, you can use the same service in a small business and use the same in large businesses as well. And cloud services have to handle the companies growing, for example a startup needs in the beginning and at the top of their up growth. While there is a clear evidence of upfront (capex) cost reduction, businesses embark on cloud for agility, elasticity, and mobility reasons.

Flexibility means how the service can conform to your company fluctuation. If you need more employee in the summertime – you want to pay only for that two or three summer months you use the cloud services. Monitoring these expected characteristics it could be not easy to provide a splendid service they want to subscribe for. Nowadays the cloud services are not so famous in Hungarian Enterprise environment. IT Management being afraid of cloud, try to bypass it, and solve IT problems in the traditional way. But on the other hand the employee uses cloud, they uses free cloud services – which have weaker SLA-s, if they have any Service Level Agreement. So companies have to solve the integrity of their IT infrastructure however their users not followed the IT policies.

Enterprises want to their IT environment less complex then it is supporting and serving the business needs. Cloud Computing can do it less complexity, and can provide a unified platform. This could be the second advantage after the first, cost.

## **ENTERPRISE SECURITY AWARENESS**

Whether a company is deploying a private or hybrid cloud, security remains a major concern. Cloud security often refers to user authentication and data protection, typically through encryption. Among the many issues is the ability to authenticate employees to control the cloud services and data they have access to. In addition, managing cloud security so that policies and compliance standards enforced within an internal network are extended to the cloud remains a challenge for many organizations. Adding to the complexity is the virtualization layer that sits between the operating system and hardware in the infrastructure of cloud service providers. That layer also must be configured, managed and secured [1].

Cloud security is a complex issue influenced by many factors and choices including: solution architecture, service model, deployment model, and hosting environment. This not only requires a solid understanding of the cloud solution but also various security domains and an expert understanding of compliance and risk management. If you are a small or medium size organization, the chances are you will embark on a public, hybrid, or community cloud solution which will provide you with more security than you would have had otherwise. The main issue is to be aware of risks and utilize the security controls offered by the cloud vendor.

Based on a wide scale spectrum Hungarian research (National University of Public Service) [2] resumes the level of IT security awareness in Hungary. The research differentiate the small and mid-size businesses, the enterprise and the public sector as well. 25 % of the under 250 employee businesses, the employees need IT security trainings. Enterprise size companies have a strategy to create the IT security awareness, users have more IT security knowledge but have more IT expectations to make their work easier and efficient. Large enterprise employees take part in a training, and they can keep the rules in cyberspace. Large enterprises have resources and budget to manage these trainings and they have IT strategy to handle trainings and educate their employee's.

Some typically cloud security alliances at Enterprise IT Environment are shown in Figure 1. The proprietary information is at risk every day; and it's not just data which can be lost. Data breaches cost money, customers, and even market share. Unfortunately, many breaches result from a lack of employee awareness of the security risks inherent in their actions.

Infrastructure Security	Data Privacy	Data Management	Integrity and Reactive Security
<ul style="list-style-type: none"> <li>Secure Computations in Distributing Programming Framework</li> <li>Security Best Practices for Non-Relational Data Stores</li> </ul>	<ul style="list-style-type: none"> <li>Privacy Preserving Data Mining and Analytics</li> <li>Cryptographically Enforced Data Centric Security</li> <li>Granular Access Control</li> </ul>	<ul style="list-style-type: none"> <li>Secure Data Storage and Transaction Logs</li> <li>Granular Audits</li> <li>Data Provenance</li> </ul>	<ul style="list-style-type: none"> <li>End-point validation and filtering</li> <li>Real time Security Monitoring</li> </ul>

**Figure 1.** Some typically cloud security alliance at Enterprise IT Environment.

## BYOD

Developing of mobile devices the demand has been growing. The users want to use their high-tech smartphones or tablets all the time. It is used during travelling – *even in a plane now* – they bring inside to the company, and try to download the company mailbox to this devices or try to connect to the company's server. More and more companies have a new policy – *every employee can bring not more than 3 own different devices into the company, typically a smartphone, a laptop and a tablet* – and get access to use it in work time too.

But, on the company side has to solve the different mobile management. By controlling and protecting the data and configuration settings for all mobile devices in the network, MDM can reduce support costs and business risks. The intent of MDM is to optimize the functionality and security of a mobile communications network while minimizing cost and downtime. With mobile devices becoming ubiquitous and applications flooding the market, mobile monitoring is growing in importance.

## PRIVACY AND DATA SECURITY IN THE CLOUD

The economic case for cloud computing has gained widespread acceptance. Cloud computing providers can build large datacenters at low cost due to their expertise in organizing and provisioning computational resources. The economies of scale increase revenue for cloud providers and lower costs for cloud users. The resulting on-demand model of computing allows providers to achieve better resource utilization through statistical multiplexing, and enables users to avoid the costs of resource over-provisioning through dynamic scaling [3, 4].

At the same time, security has emerged as arguably the most significant barrier to faster and more widespread adoption of cloud computing. This view originates from perspectives as diverse as academia researchers, industry decision makers [5], and government organizations. For many business-critical computations, today's cloud computing appears inadvisable due to issues such as service availability, data confidentiality, reputation fate sharing, and others.

## HOW TO TEACH CLOUD SECURITY FOR CONSUMER?

First of all teaching cloud security is the most important task we have to manage. Security questions are here, the treatment of the cyberspace are frightened us. Any IT devices, software, hardware are reachable for everybody, and you cannot mention any kind of job not using an IT application via Internet. IT became an essential service, and all of part of business

and private life to use IT and cannot manage a lot of action without IT service. Cloud computing brings new training and learning tools to education. Teachers or trainers reach their students in an easy way in different platforms, for example the web conference, social community sites, common sites, hosting sites or they can evolve closed user group for a training teams.

Cloud computing advantages bring new possibilities in studying for students as well. They have anywhere and anytime access, the students can apply for different universities, or listen in a foreign course. The borders disappear, there is no physical barrier, and there is no distance between students in different universities, different countries. Students can use any device they have and connect easily to the university cloud. Studying can be supported a sort of interactive or online elements, they can solve problems commonly or work together on a same project using co-working apps. I like to mention and other advantages of using cloud at the university, student can get several cloud skills which are good experience – and usable for a job application. Students take part in foreign scholarships or foreign project without traveling abroad.

In Hungary some university have started to use advantages of the cloud. For example the Óbuda University started a course in 2014, which is available for students at partner universities. The Informatics Faculty of ELTE was the first in Hungary moved to the cloud, providing several features to its students. The Miskolci University and the Debreceni University had moved to the cloud and provide their students mailbox, SharePoint sites, OneDrive cloud storage with 1 TB, and professional web conference with presence and chat functions. The underlying research asks how the IT security awareness could be extend, what different didactics we have and what are of them effectiveness for users. It is tempted to size up the average knowledge, and to try different learning tools and follow up the effectiveness of the different tools [6].

## **ONLINE TRAININGS VS. PERSONAL TRAININGS**

Online trainings can produce great results by decreasing costs and improving performance. Also, unlike a onetime classroom session, the e-learning course is available for others. Online or E-learning trainings improve training costs, each time the course is accessed your return on investment improves because you are dividing the fixed production costs by number of uses. You also have savings through decreased travel, reduced material, and hopefully improved (and more efficient) performance [7].

E-learning is not bound by geography or time, you can control training's impact on production by training people during down times. In addition, with the current economy, you're asking people to do more with less. So e-learning is a great way to give them the tools and skills needed to enhance their performance. E-learning allows you to create a standardized process and consistency in the delivery of content. It also compresses delivery time. We have combined e-learning courses with facilitated sessions. E-learning delivered consistent content. Live sessions were interactive case studies that applied the information.

Personal training has different advantages, you can get a real-time feedback, and you can check the level of the students and shape the content to the students need. You can give a soul to the content or emphasize the logical skeleton. You can answer their question and realize the trammels and you can help them to overtake that trammels. Yes, it is cost a lot, it has personal limit, and you can find a suitable place and a suitable time for all of the participants.

One opinion is that the aforementioned didactic elements, to be mixed together, need a smart selection of the content, and alternate the tools, to create a balance in the education.

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## KRETANJE PREMA SIGURNOSTI OBLAKA

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### SAŽETAK

Računalni oblaci sadrže i isporučuju više različitih internetskih usluga. Više je razloga zbog kojih se odlučuju koristiti resurse računalnih oblaka. Razvoj oblaka se ubrzava i za njime kasni mnoštvo pridruženih usluga poput svjesnosti mase i sigurnosti oblaka. Nove generacije, npr. bez razloga pohranjuju video snimke i fotografije u resursima oblaka, dok ih je samo neznatan broj upoznat s pojmovima privatnost podataka, upravljanje podacima i vlasništvo podataka pohranjenih u računalnom oblaku. U poduzetničkom okruženju korisnici moraju biti upoznati s pravilima korištenja računalnih oblaka ali su oskudnog znanja o tradicionalnoj sigurnosti informacijskih tehnologija. Bitno je mjeriti razinu njihovog znanja i razvijati sustav učenja kako bi povećavao svjesnost o sigurnosti.

Rad dokazuje značajnost predlaganja novih metrika i algoritama mjerjenja svjesnosti o sigurnosti za korporativne korisnike i zaposlenike kako bi se odgovarajući zahtjevi uključili u razvijajuću sigurnost računalnih oblaka.

### KLJUČNE RIJEĆI

sigurnost oblaka, informatičke tehnologije

# **SYNOPSIS OF SOFT COMPUTING TECHNIQUES USED IN QUADROTOR UAV MODELLING AND CONTROL**

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## **ABSTRACT**

The aim of this article is to give an introduction to quadrotor systems with an overview of soft computing techniques used in quadrotor unmanned aerial vehicle (UAV) control, modelling, object following and collision avoidance. The quadrotor system basics, its structure and dynamic model definitions are recapitulated. Further on synopsis is given of previously proposed methods, results evaluated and conclusions drown by authors of referenced publications. The result of this article is a summary of multiple papers on fuzzy logic techniques used in position and altitude control systems for UAVs. Also an overview of fuzzy system based visual servoing for object tracking and collision avoidance is given together with a briefing of quadrotor UAV control techniques efficiency study.

Conclusion is that though soft computing methods are widely used with good results, there is still place for much research to be done on find more efficient soft computing tools for simple modelling, robust dynamic control and fast collision avoidance in quadrotor UAV control.

## **KEY WORDS**

UAV, quadrotor, control, soft computing, fuzzy logic

## **CLASSIFICATION**

ACM: G.1.6

JEL: Z19

PACS: 45.40.-f, 87.19.lu

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## INTRODUCTION

A wide area of robotics research is dedicated to aerial platforms. Multiple structures and configurations have been developed to allow 3D movements [1-14]. For example, there are blimps, fixed-wing planes, single rotor helicopters, bird-like prototypes, quadrotors, etc. Each of these has advantages and drawbacks. The vertical take-off and landing requirements exclude some of the aforementioned configurations [1, 2].

The quadrotor architecture has low dimensions, good manoeuvrability, simple mechanics and payload capability. The main drawback is the relatively high energy consumption; however the trade-off results are very positive. This structure can be attractive in several applications, in particular for surveillance, for imaging dangerous environments, and for outdoor navigation and mapping [1, 2]. The study of kinematics and dynamics helps to understand the physics of the quadrotor and its behaviour [3, 4]. Together with modelling, the determination of the control algorithm structure is very important. Soft computing methods can be efficiently applied together with and also instead of conventional controllers [2].

The article is organized as Section 1: introduction. Section 2: modelling of the quadrotor unmanned aerial vehicles. In Section 3 fuzzy logic based control and modelling strategies for path tracking, position and altitude control of UAVs are briefed. In Section 4 fuzzy system based visual servoing is summarised. In Section 5 a control techniques efficiency study is briefed. Conclusions are given in Section 6. References are in Section 7.

## MODELLING OF QUADROTOR UNMANNED AERIAL VEHICLES

As is well summarised in [1, 2] rotary wing aerial vehicles have distinct advantages over conventional fixed wing aircrafts in surveillance and inspection tasks because they can take-off and land in limited spaces and easily fly above the target. A quadrotor is a four rotor helicopter. An example of one is shown in Figure 1. Helicopters are dynamically unstable and therefore suitable control methods are needed to make them stable. Although unstable dynamics is not desirable, it is good from the agility point of view. The instability comes from changes in the helicopter parameters and from disturbances such as a wind gust or air density variation [1, 2]. A quadrotor helicopter is controlled by varying the rotor speed, thereby changing the lift forces [3, 4]. It is an under-actuated dynamic vehicle with four input forces and six outputs coordinates. One of the advantages of using a multi-rotor helicopter is the increased payload capacity. Quadrotors are highly manoeuvrable, which allows for vertical take-off and landing, as well as flying into hard-to-reach areas. Disadvantages are the increased helicopter weight and increased energy consumption due to extra motors. Since the machine is controlled via rotor speed changes, it is more suitable to utilize electric motors. Large helicopter engines, which have a slow response, may not be satisfactory without incorporating a proper gear-box system [1, 2].

Unlike typical helicopter models (and regular helicopters), which have variable pitch angles, a quadrotor has fixed pitch angle rotors, and the rotor speeds are controlled in order to produce the desired lift forces [1, 2].

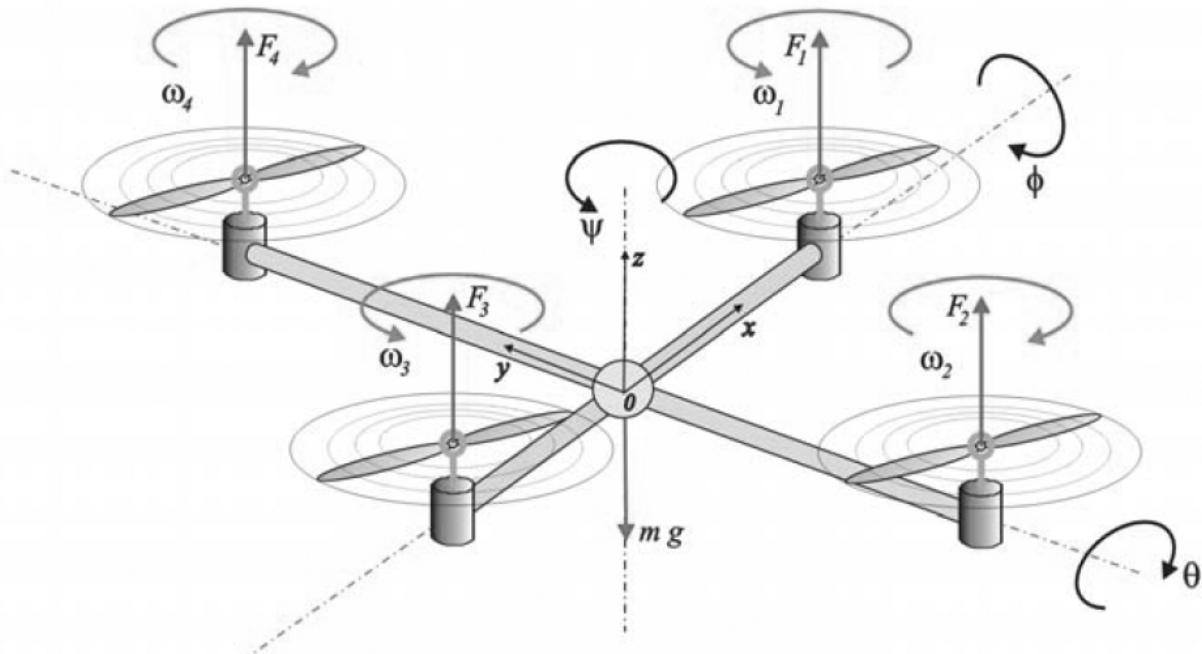
The quadrotor is satisfactorily well modelled [1-12] with a four rotors in a cross configuration as presented in Figure 1. This cross structure is quite thin and light, however it shows robustness by linking mechanically the motors (which are heavier than the structure). Each propeller is connected to the motor through the reduction gears. All the propellers axes of rotation are fixed and parallel. Furthermore, they have fixed-pitch blades and their air flows

point downwards (to get an upward lift). These considerations point out that the structure is quite rigid and the only things that can vary are the propeller speeds.

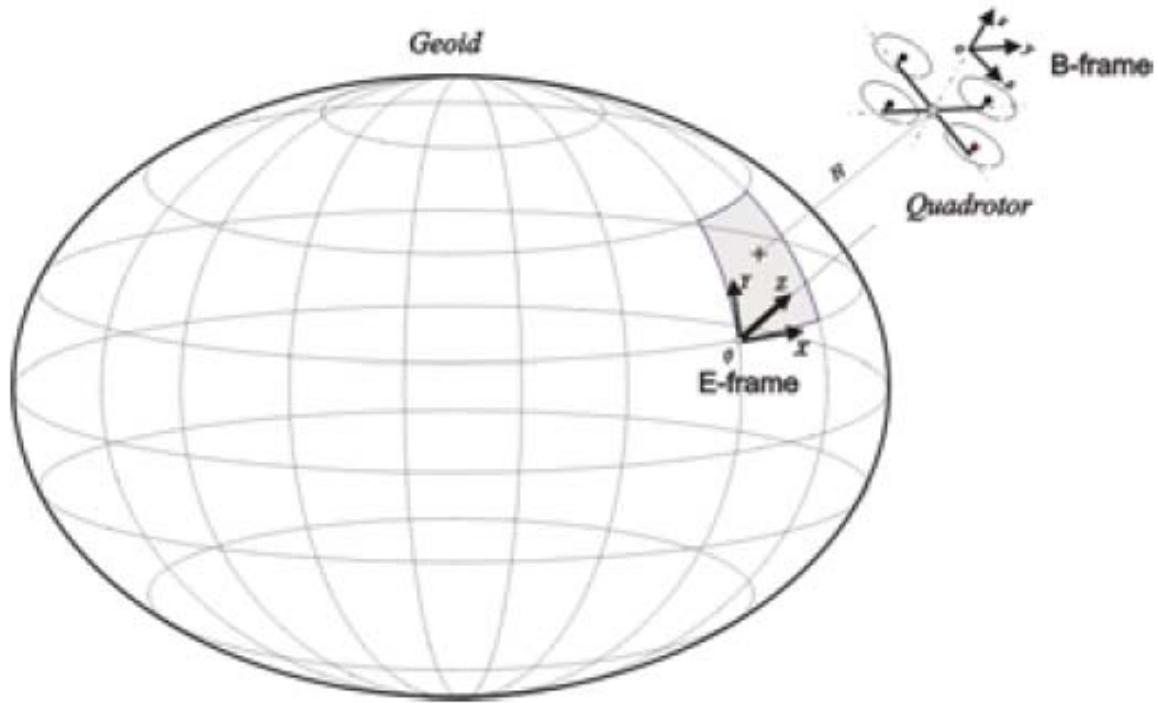
As shown in Figure 1, one pair of opposite propellers of quadrotor rotates clockwise (2 and 4), whereas the other pair rotates anticlockwise (1 and 3). This way it is able to avoid the yaw drift due to reactive torques. This configuration also offers the advantage of lateral motion without changing the pitch of the propeller blades. Fixed pitch simplifies rotor mechanics and reduces the gyroscopic effects. Control of quadrotor is achieved by commanding different speeds to different propellers, which in turn produces differential aerodynamic forces and moments. For hovering, all four propellers rotate at same speed. For vertical motion, the speed of all four propellers is increased or decreased by the same amount, simultaneously. In order to pitch and move laterally in that direction, speed of propellers 3 and 1 is changed conversely. Similarly, for roll and corresponding lateral motion, speed of propellers 2 and 4 is changed conversely. To produce yaw, the speed of one pair of two oppositely placed propellers is increased while the speed of the other pair is decreased by the same amount. This way, overall thrust produced is same, but differential drag moment creates yawing motion. In spite of four actuators, the quadrotor is still an under-actuated system [1, 2].

To describe the motion of a 6 DOF rigid body it is usual to define two reference frames: the earth inertial frame (E-frame), and the body-fixed frame (B-frame) – see Figure 2. Equations of motion are more conveniently formulated in the B-frame because the inertia matrix is time-invariant, advantage of body symmetry can be taken to simplify the equations, measurements taken on-board are easily converted to B-frame and control forces are readily available in the B-frame [1, 2].

The E-frame (OXYZ) is chosen as the inertial right-hand reference. Y points toward the North, X points toward the East, Z points upwards with respect to the Earth, and O is the axis origin. This frame is used to define the linear position (in meters) and the angular position (in radians) of the quadrotor. The B-frame (oxyz) is attached to the body. x points toward the quadrotor front, y points toward the quadrotor left, z points upwards and o is the axis origin. The origin o is chosen to coincide with the center of the quadrotor cross structure. This reference



**Figure 1.** 3 D motion, commonly used model of the quadrotor.



**Figure 2.** Earth- and Body-frame used for modelling of the quadrotor system.

reference is right-hand, too [1, 2]. The linear velocity  $v$  (m/s), the angular velocity  $\Omega$  (rad/s), the forces  $F$  (N) and the torques  $T$  (N m) are defined in this frame. The linear position of the helicopter ( $X, Y, Z$ ) is determined by coordinates of the vector between the origin of the B frame and the origin of the E-frame according to the equation. The angular position (or attitude) of the helicopter ( $\phi, \theta, \psi$ ) is defined by the orientation of the B-frame with respect to the E-frame. This is given by three consecutive rotations about the main axes which take the E-frame into the B-frame. The “roll-pitch-yaw” set of Euler angles can be used. The vector that describes the quadrotor position and orientation with respect to the E-frame can be written in the form [1, 2]:

$$s = [X \ Y \ Z \ \phi \ \theta \ \psi]^T, \quad (1)$$

The rotation matrix between the E- and B-frames has the following form [5]:

$$R = \begin{bmatrix} c_\psi c_\theta & -s_\psi c_\phi + c_\psi s_\theta s_\phi & s_\psi s_\phi + c_\psi s_\theta c_\phi \\ s_\psi c_\theta & -c_\psi c_\phi + s_\psi s_\theta s_\phi & -c_\psi s_\phi + s_\psi s_\theta c_\phi \\ -s_\theta & c_\theta s_\phi & c_\theta c_\phi \end{bmatrix}. \quad (2)$$

The corresponding transfer matrix has the form:

$$T = \begin{bmatrix} 1 & s_\phi t_\theta & c_\phi t_\theta \\ 0 & c_\phi & -s_\phi \\ 0 & s_\phi/c_\theta & c_\phi/c_\theta \end{bmatrix}. \quad (3)$$

In the previous two equations (and in the following) this notation has been adopted:  $s = \sin(\cdot)$ ,  $c = \cos(\cdot)$ ,  $t = \tan(\cdot)$ . The system Jacobian matrix, taking (2) and (3), can be written in the form:

$$J = \begin{bmatrix} R & \mathbf{0}_{3 \times 3} \\ \mathbf{0}_{3 \times 3} & T \end{bmatrix}, \quad (4)$$

where  $0_{3 \times 3}$  is a zero-matrix. The generalized quadrotor velocity in the B-frame has a form:

$$\mathbf{v} = [\dot{x} \quad \dot{y} \quad \dot{z} \quad \dot{\phi} \quad \dot{\theta} \quad \dot{\psi}]. \quad (5)$$

Finally, the kinematical model of the quadrotor can be defined in the following way [1, 2]:

$$\dot{\mathbf{s}} = \mathbf{J} \cdot \mathbf{v}. \quad (6)$$

The dynamics of a generic 6 DOF rigid-body system takes into account the mass of the body  $m$  (kg) and its inertia matrix  $\mathbf{I}$  ( $N \cdot m \cdot s^2$ ). Two assumptions have been done in this approach :

- the first one states that the origin of the body-fixed frame is coincident with the centre of mass (COM) of the body. Otherwise, another point (COM) should be taken into account, which could make the body equations considerably more complicated without significantly improving model accuracy [1, 2],
- the second one specifies that the axes of the B-frame coincide with the body principal axes of inertia. In this case the inertia matrix  $\mathbf{I}$  is diagonal and, once again, the body equations become simpler [1, 2].

The dynamic model of a quadrotor can be defined in the following matrix form:

$$\mathbf{M}_B \ddot{\mathbf{v}} + \mathbf{C}_B(\mathbf{v})\dot{\mathbf{v}} - \mathbf{G}_B = \Lambda, \quad (7)$$

where  $\mathbf{M}_B$  is the system Inertia matrix,  $\mathbf{C}_B$  represents the matrix of Coriolis and centrifugal forces and  $\mathbf{G}_B$  is the gravity matrix. These matrices have known forms as presented in [5].

A generalized force vector  $\Lambda$  has the form:

$$\Lambda = \mathbf{O}_B(\mathbf{v})\Omega + \mathbf{E}_B\Omega^2, \quad (8)$$

where:

$$\mathbf{O}_B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \theta & -\theta & \theta & -\theta \\ -\dot{\phi} & \dot{\phi} & -\dot{\phi} & \dot{\phi} \\ 0 & 0 & 0 & 0 \end{bmatrix}, \quad (9)$$

is the gyroscopic propeller matrix and TP  $J$  is the total rotational moment of inertia around the propeller axis. The movement aerodynamic matrix has the form [1, 2]:

$$\mathbf{E}_B = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ b & b & b & b \\ 0 & -b \cdot l & 0 & b \cdot l \\ -b \cdot l & 0 & b \cdot l & 0 \\ -d & d & -d & d \end{bmatrix}, \quad (10)$$

where  $b$  ( $N \cdot s^2$ ) and  $d$  ( $N \cdot m \cdot s^2$ ) are thrust and drag factors, respectively, and  $l$  (m) is the distance between the centre of the quadrotor and the centre of the propeller. Equation (11) defines the overall propellers' speed ( $\text{rad s}^{-1}$ ) and the propellers' speed vector ( $\text{rad s}^{-1}$ ) used in equation (8).

$$\omega = -\omega_1 + \omega_2 - \omega_3 + \omega_4, \quad (11)$$

$$\Omega = [\omega_1 \quad \omega_2 \quad \omega_3 \quad \omega_4]^T. \quad (12)$$

Equations (1)-(12) take into account the entire quadrotor non-linear model including the most influential effects [1, 2].

## PATH TRACKING

The nonlinear, multivariable and coupled characteristics make the quadrotor difficult to control. In a general approach two loops are used for the quadrotor UAV control system: the outer loop is the position controller and the inner loop is the attitude controller. The controller of outer loop for position includes information such as instantaneous position and speed. While the inner loop for attitude controller includes the posture information.

The position controller receives as inputs the difference between the desired position (X,Y,Z) and current position, the outputs are the desired angles ( $\phi$ ,  $\theta$ ,  $\psi$ ) to move towards the desired position, and it is provided for the attitude controller in the inner loop. The attitude controller outputs the desired rotor speed to the motor controller.

## PID CONTROLLERS WITH FUZZY SYSTEMS BASED ADAPTIVE GAIN PARAMETERS

As described in [13, 14] fuzzy logic systems can be used for adaptive tuning of PID controllers for stabilisation and path tracking of quadrotor UAVs. A PID controller consists of a proportional, an integral and a derivative feedback control action, which represent the current, past and anticipated future errors that cover all the time history of the error signal. The relevant gains are KP, KI and KD. By adjusting these parameters, the performance and stability of the system can be achieved. The mathematical representation of PID controller is given as:

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau) d\tau + K_D \frac{d}{dt} e(t). \quad (13)$$

With fixed three gain parameters a PID controller provides good performance only for linearized systems in a narrow operation range. To overcome the nonlinearity problem fuzzy logic systems can be used for adaptive tuning of PID gain parameters [16, 17]. Fuzzy logic consists of four components: fuzzyfication, fuzzy ruled base, inference engine, and defuzzyfication:

- fuzzyfication refers to the process of transforming crisp input values into grades of membership using linguistic terms of fuzzy sets,
- fuzzy rule base is the main part of fuzzy logic systems. This component is based on if-then rules. The fuzzy rule base defines how to react on each input combination,
- inference engine applies the fuzzy rule base to form the output for defuzzyfication,
- defuzzyfication is a method to obtain numerical data from the output of a fuzzy rule base.

For a self-tuning fuzzy PID controller the tracking error can be considered as an input for two controllers: once for a classical PID control algorithm to minimize error position, and also to a fuzzy logic system for adjusting KP, KI, and KD gain parameters of the PID controller (13).

In [13] 3 fixed position and size triangular membership functions (MFs) were used for fuzzyfication of the error signal as input and for the gain parameter output; a fixed set of 3 fuzzy rules were defined. Results of [13] show that the performance of both the classical PID and the fuzzy logic based self-tuning PID control method is acceptable in static cases of no load variation. The self-tuning PID control based on fuzzy logic is able to compensate for variations in payload to achieve good path tracking. The classical PID control algorithm by itself cannot track the circular path while the self-tuning PID base on fuzzy logic provides a good performance solution also for this problem [13].

In [14] a wide range of disturbances are modelled. Gravity and buoyancy are combined into a single force. The fluid inertia force related to the acceleration of the airship motion is represented by additional mass. In the body coordinate system the direction of the lift force

remains constant. While in the inertial system the driving force of lift is decomposed into three directions along the three coordinate axes. The quadrotor airship is more susceptible to influence of air resistance during flight because of its large surface area. In [14] six fuzzy adaptive controllers are proposed for tuning the gain parameters of PID controllers, one control output for each state variable of (1). For each fuzzy adaptive controller in [14] seven fixed MFs (of Z, S and triangular types) are defined for input fuzzyfication and output defuzzyfication. The fuzzy rule base is defined constant by expert knowledge. Results in [14] show that for a quadrotor airship model the fuzzy adaptive PID algorithm has a better performance than the classical PID control system.

## LYAPUNOV STABLE BACKSTEPPING CONTROL WITH AN ADAPTIVE FUZZY MODEL

In [15] it is presented how a robust control method with an adaptive fuzzy model can overcome wind disturbance, which buffet the vehicle with periodic wind vortices. For adaptive-fuzzy altitude control of the roll, pitch, and yaw the nonlinear functions of (6) are modelled by fuzzy systems. The notation used is as follows – from (8)  $\Lambda = [u_1, u_2, u_3, u_4]$ ; from (1)  $\dot{x} = [s \dot{s}]$  so that the system (6) becomes  $\dot{x} = f(x, u)$  as:

$$\dot{x} = f(x, u) = \begin{pmatrix} x_{10} \\ x_{11} \\ x_{12} \\ x_{10}x_{12}a_1 + x_{10}a_2O + b_1u_2 \\ x_5x_{12}a_3 + x_5a_4O + b_2u_3 \\ x_{10}x_5a_5 + b_3u_4 \\ x_9 \\ x_7 \\ x_8 \\ -g + c_{x_1}c_{x_3}u_1/m \\ g(x)u_1/m \\ h(y)u_1/m \end{pmatrix} \quad (14)$$

where  $I_{X,Y,Z}$  are body inertia terms. The  $J_r$  rotor inertia term is used with lever  $l$  as:

$$a_1 = \frac{I_Y - I_Z}{I_X}, a_2 = -\frac{I_r}{I_X}, a_3 = \frac{I_Z - I_X}{I_Y}, a_4 = \frac{I_r}{I_Y}, a_5 = \frac{I_X - I_Y}{I_Z}, b_1 = \frac{l}{I_X}, b_2 = \frac{l}{I_Y}, b_3 = \frac{l}{I_Z}, g(x) = (c_{x_4}s_{x_5}c_{x_6} + s_{x_4}s_{x_5}s_{x_6}), h(y) = (c_{x_4}s_{x_5}s_{x_6} - s_{x_4}c_{x_6}) \quad (15)$$

In [15] the fuzzyfication encoding of angular position error inputs  $x$  consists of normalized Gaussian MFs with centres placed on a fixed, evenly spaced lattice and of widths  $\sigma$  like

$$\Gamma_t(x) = \frac{\exp(-(C_t - x)^T(C_t - x)/\sigma^2)}{\sum_{t=1}^N \exp(-(C_t - x)^T(C_t - x)/\sigma^2)},$$

where each  $c_i$  is a centre on the lattice and  $N$  is the number of MFs. The decoding of control outputs is accomplished with one dimensional Gaussian MFs with widths  $\sigma$ , but with centres that can be changed adaptively. The output of the decoding is

$$\Gamma^T c = [\Gamma_1 \Gamma_2 \dots \Gamma_N] \cdot [c_1 c_2 \dots c_N]^T,$$

where  $c \in \mathbb{R}^N$  is a vector of output MF centres. According to the standard approximation theory, if the density of encoding lattice points is high enough then the output of the decoding scheme can uniformly approximate nonlinear functions in a local region as  $x_k = \Gamma_t^T(x)c_t + \epsilon_t(x)$  where  $k = 4, 5, 6$  for  $i = 1, 2, 3$ . Thus  $\epsilon_t(x) \leq \epsilon_{\max}$  the approximation error of nonlinear functions is bounded. If the actual centres of output MFs are  $\tilde{c}$  the error

between actual and ideal centres is  $\tilde{c} = c - \dot{c}$ . By taking filtered tracking errors  $z_t = Lx_t + x_{(t+3)}$  for  $i=1,2,3$  where  $L$  is a positive constant, the following Lyapunov control function can be defined as  $V(z, \tilde{c}) = \sum_{i=1}^3 (z_i^2 + \tilde{c}_i^T \tilde{c}_i)/2$ . Assuming there is a bounded external disturbance the derivative of  $V$  is bounded and Lyapunov stability of the proposed control method is presented in [15]. The resulting control is stable, computationally efficient, and theoretically robust to disturbance. It achieves high performance while eliminating centre drift [15].

## DIRECT PD LIKE FUZZY CONTROLLERS FOR POSITION AND ALTITUDE CONTROL

In [18] a direct fuzzy PD controller approach is used for altitude control and path tracking of a quadrotor UAV. To control each 3 angular position error a normalized input/output Sugeno type fuzzy engine was used with 3 MFs on both input and output and a fixed rule base defined by expert knowledge. The fuzzy attitude control design proposed in [18] was verified within simulations by comparison to a back-stepping approach control design. Path tracking efficiencies are very similar for both attitude control systems. In [18] the proposed fuzzy attitude control revealed slightly better performance in case of a rapid trajectory direction changes. The only significant difference was in the first segment of the flight, where the proposed fuzzy solution obtains the desired trajectory much faster than the back-stepping solution [18].

In [19] a PD like fuzzy controller is described for position control to compensate for nonlinear disturbance such as the wind. For the position controller of the robot, there are two inputs to the fuzzy logic controller. The first is the error, which is the difference between the target position of the robot and actual position of the robot. The second input is the first derivative of error with respect to time  $\dot{e}$ . Then the fuzzy controller outputs the force for moving to the target position. For the output of fuzzy controller in [19] a simplified fuzzy inference method is used with fixed MFs and an expert knowledge based fuzzy rule set is defined. The result in [19] is that the proposed fuzzy controller is more suitable for path tracking in outdoor condition than a simple PD controller. But the proposed fuzzy controller still presented not so good results for the response and steady-state error when a fair wind was blowing.

## FUZZY CONTROL SYSTEM BASED VISUAL SERVOING

Computer vision techniques can provide UAVs with an additional source of information to perform visually guided tasks like tracking and visual servoing, inspection, pursuit and flying in formations. [20] presents a fuzzy servoing strategy using a real time flying objects following method based only on visual information to generate commands in a dynamic look and move control architecture. Considering a flying object moving with an unknown trajectory on the world space, and a flying robot with an attached fixed calibrated pinhole camera, both having an idealized flying dynamics. The control goal is to command the flying robot in order to track the target object, maintaining it always onto the camera focus with a fixed separation distance. The target is modelled as an ideally spherical surface, the projection point can be considered as the image projection of target's sphere centroid with coordinates on the camera frame. The projected diameter also can be used to estimate the distance to the target, because it is inversely proportional to the distance from the camera to the object. In [20] the problem of tracking is approached by exploiting the colour characteristic of the target. A basic colour is defined to the target by assuming a simple coloured mark to it and tracking this mark. This process is not always perfect, and changes still occur in colour distributions over time. An algorithm that has proven to deal with this issue by dynamically adapting to changes in probability distributions is the Continuously Adaptive Mean Shift [21]. This algorithm is based in the mean shift originally introduced by Fukunaga and Hostetler [22]. In [20] two Mamdani Fuzzy controllers were used that are

based on the visual information previously described to generate yaw and pitch commands for the UAV. All the variables of the two controllers are defined using triangular membership functions. The complete controller design is fixed, based on expert knowledge. Both controllers have two inputs and one output. The controller of the yaw or heading of the UAV has for the first input the angle estimation in radians, between the UAV and the centre of the image and the centre of the object to follow. The second input is the difference between the last angle estimation and the actual angle. This controller sends velocity commands (degrees per seconds) for change of the heading position of the aircraft. The second controller acts on the pitch state of the UAV. It takes the data about the size of the object in pixels, to follow and estimate the distance. Using as the first input the actual size of the object and as the second input the difference between the last size measure and the actual size is taken. The output of the controller is velocity commands to go ahead, in the case that the object is far away; stay in the same position if the object is near at a predefined safe; or go back if it is very close to the UAV. Real tests on outdoors scenarios demonstrated the excellent behaviour of fuzzy controllers, which were generating yaw and pitch commands based on visual information, performing the action of tracking the target object from a safe distance [20].

In [23] the same setup was used as in [20]. A Fuzzy Logic controller based on expert knowledge has been developed to automatize the collision avoidance. This controller acts changing the heading of the aircraft, keeping the obstacle to avoid at the right side (or left) of the image until the object can be overtaken. Excellent results have been obtained in real tests using a commercial quadrotor with a quick response and low error estimation [23].

## FUZZY CONTROLLER PERFORMANCE

In [2] benchmarking and qualitative evaluation of different autonomous quadrotor flight controllers is presented. Three characteristic representatives of frequently used flight control techniques are considered: PID, backstepping and fuzzy. Dynamic performances, trajectory tracking precision, energy efficiency and control robustness upon stochastic internal and/or external perturbation was considered. Two experimental scenarios are considered as the characteristic benchmarking procedures: dynamic quadrotor flight in the 3D-loop manoeuvre, and a typical cruising flight along the trajectory introduced by setting waypoints with the pre-defined GPS coordinates. In case of fuzzy control six Takagi-Sugeno-Kand fuzy systems were used, one for each state variable in (1). Each fuzzy system has 2 inputs, error and error rate, fuzzyfication with 3 fixed triangular membership functions, 3 singletons were used for output MFs. A fixed rule base is defined based on expert knowledge. Analysing the simulation results the backstepping method ensures the best control performances in sense of trajectory tracking precision. The other two concurrent algorithms have slightly better characteristics in sense of energy efficiency (having lower energy consumption). By increasing of flight speed dynamic effects become influential upon the system performances: the backstepping method is more sensitive to changing of flight speed than other two controllers PID and fuzzy logic controllers [2].

## CONCLUSIONS

Fuzzy logic based controllers can be able to compensate for variations in payload and to achieve good path tracking; they can also track circular paths [13]. A fuzzy adaptive PID algorithm has a better effect than the classical PID control system by itself [14]. Fuzzy logic based controls can be made Lyapunov stable, computationally efficient, and theoretically robust to disturbance. They can achieve high performance while eliminating centre drift [15]. Fuzzy logic control solutions can obtain the desired trajectory much faster than the backstepping control solution [18].

A fuzzy controller is more suitable for path tracking in outdoor condition than a simple PD controller; still it is insufficient for the response and steady-state error control when a fair wind is blowing [19].

Real tests on outdoors scenarios proved the excellent behaviour of the fuzzy controllers for yaw and pitch performing the action of tracking the target object from a safe distance [20] as well as for collision avoidance [23].

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## PREGLED TEHNIKA MEKOG RAČUNALSTVA KORIŠTENIH U MODELIRANJU I KONTROLI BESPILOTNIH LETJELICA KVADROTORA

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### SAŽETAK

Cilj rada je davanje uvoda u kvadrotore s pregledom tehnika mekog računalstva korištenih za kontrolu, modeliranje, praćenje objekata i izbjegavanje sudara bespilotnih letjelica kvadrotora. Navedene su osnove sustava kvadrotora, njegova struktura i dinamički model. Nadalje, naznačeni su postojeće metode, evaluirani njihovi rezultati i zaključci koje su publicirali drugi istraživači. Rezultat rada je kompilacija više radova na temu korištenja neizrazite logike za kontrolu pozicije i visine bespilotnih letjelica. Također, dan je pregled vizualne podloge praćenja objekata i izbjegavanja sudara temeljene na neizrazitim sustavima, zajedno s pregledom istraživanja učinkovitosti tehnika kontrole bespilotnih letjelica.

Zaključak je da, iako su metode mekog računalstva široko korištene s dobrim rezultatima, postoji znatan prostor za daljnja istraživanja i nalaženje učinkovitijih alata mekog računalstva za jednostavno modeliranje, robusnu dinamičku kontrolu i brzo izbjegavanje sudara u kontroli bespilotnih letjelica kvadrotora.

### KLJUČNE RIJEČI

UAV, kvadrotor, kontrola, meko računarstvo, neizrazita logika

# CLOUD ROBOTICS PLATFORMS

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## ABSTRACT

Cloud robotics is a rapidly evolving field that allows robots to offload computation-intensive and storage-intensive jobs into the cloud. Robots are limited in terms of computational capacity, memory and storage. Cloud provides unlimited computation power, memory, storage and especially collaboration opportunity. Cloud-enabled robots are divided into two categories as standalone and networked robots. This article surveys cloud robotic platforms, standalone and networked robotic works such as grasping, simultaneous localization and mapping (SLAM) and monitoring.

## KEY WORDS

cloud, cloud robotics, cloud computing, cloud platform, networked robots

## CLASSIFICATION

ACM: D.1.1.

JEL: O39

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## INTRODUCTION

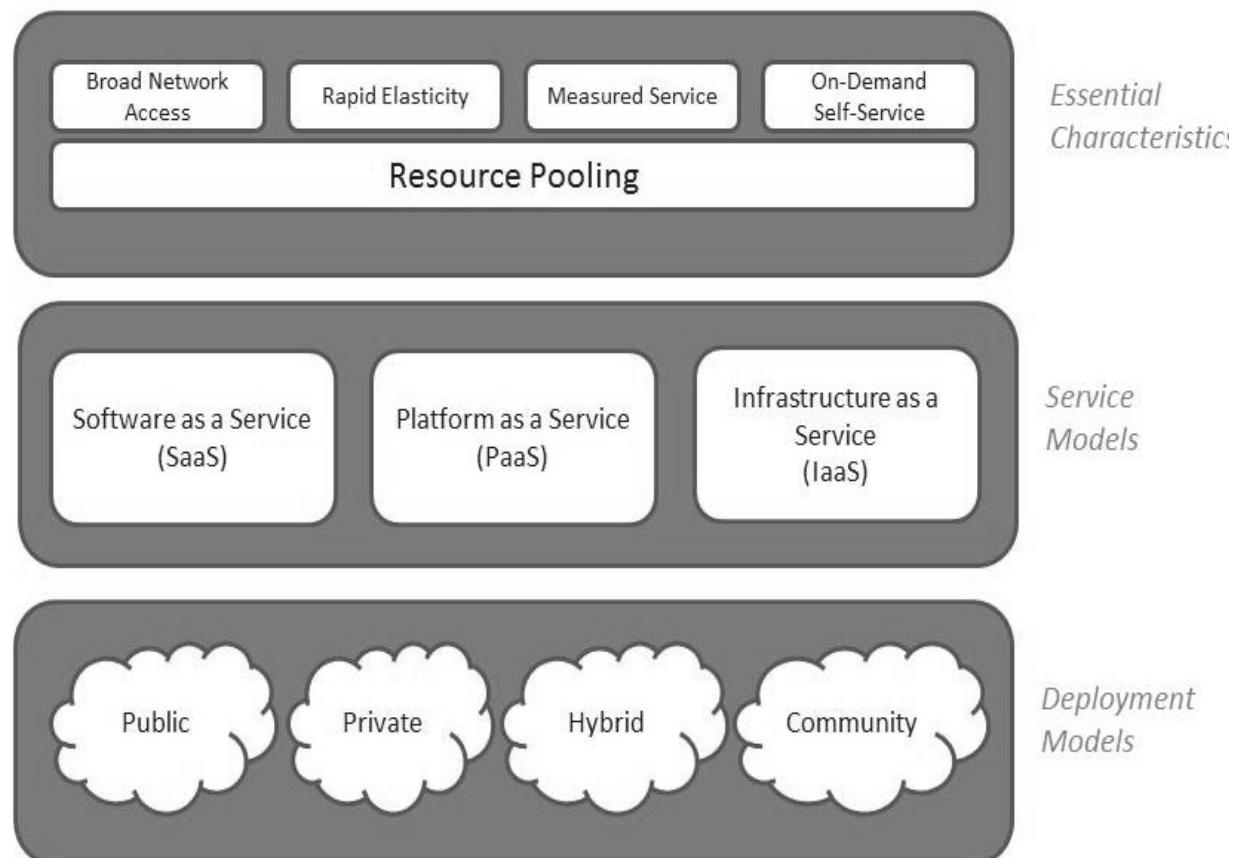
Cloud Robotics (CR) is a term combination of cloud technologies and robotics. Robots empowered with cloud technologies have been an important part of our daily lives. NIST [1] defines cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.”

Cloud computing consist of three fundamental models as Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) as shown in Figure 1.

SaaS applications are served over the internet, thus eliminating the need to install and run the application on the users system [2]. They are managed from a centralized location and accessed remotely by a web browser or a mobile client. Google Apps is the most widely used SaaS application suit.

PaaS refers to a computing platform served by cloud infrastructure. PaaS offers developers to get a hold of all the systems and environments required for the life cycle of software, be it developing, testing, deploying and hosting of web applications. Some examples are Amazon Web Services (AWS) [3] and Microsoft’s Azure [4].

IaaS provides the required infrastructure as a service. The client need not purchase the required servers, data center or the network resources. The essence of IaaS model is a pay-as-you-go financial model. Amazon and Microsoft are also IaaS providers.



**Figure 1.** Cloud computing infrastructure.

Robots make significant socioeconomic impacts to human lives [5, 6]. For example, robots can do repetitive or dangerous tasks, such as assembly, painting, packaging, and welding.

However, robots are limited in terms of computational capacity, memory and storage. Also they have physical constraints such as size, shape, power supply, motion mode and working environment [7-9]. Robots are usually used for industrial purposes, they are not commonly used in daily life because of their cost. Cloud computing can be used to enhance robots' capabilities.

Cloud computing technologies provide numerous advantages that can be valuable for the composition and running robot services. For example, complex computations of computation intensive applications can be offloaded in the cloud like what is done for Apple's voice recognition service "Siri". Connecting the robots to semantic knowledge databases hosted in the cloud will allow a large number of heterogeneous robots to share common sense knowledge [10-12].

The concept of "robot-as-a-service" (RaaS) refers to robots that can be dynamically combined to give support to the execution of specific applications. RaaS has three aspects of the system: structure, interface, and behavior. There can be many kinds of robot cloud units or intelligent devices. For example, robot cops [13], restaurant robot waiters [14], robot pets [15], and patient care robots [16]. These robots are distributed in different locations and can be accessed through CR platforms.

The article is organized as follows:

- section 1, introduction,
- in Section 2, cloud robotics platforms are illustrated,
- cloud-enabled robots are given in Section 3, and
- conclusions are given in Section 4.

## CLOUD ROBOTICS PLATFORMS

Developing software solutions for robots is difficult, because of varying hardware and non-standardized APIs. Robotics researchers, have created a variety of frameworks to manage complexity and facilitate rapid prototyping of software for experiments, resulting in the many robotic software systems currently used in academia and industry [17].

Stanford University and Willow Garage developed a generalized open source operating system called Robot Operating System (ROS) for robots [18]. ROS is not only an operating system; rather, it provides a structured communications layer above the host operating systems of a heterogeneous compute cluster [19].

Rapyuta is an open-source cloud robotics platform. It serves a platform-as-a-service (PaaS) framework for robots. Rapyuta architecture depends on LxC [20] containers. It provides an environment to access RoboEarth [21] Knowledge Repository. Massively parallel computation, allowing humans to monitor or intervene robots and serving as a global repository to store and share object models, environment maps, and actions recipes between various robotic platforms are some of specifications of Rapyuta. It is a competitor of Rosbridge [22] in terms of communication [23].

Survivable Cloud Multi-Robotics (SCMR) Framework is designed, implemented and evaluated for heterogeneous environments. One of the challenges for cloud robotics is the inherent problem of cloud disconnection. The SCMR framework provides the combination of a virtual Ad-hoc network formed by robot-to-robot communication and a physical cloud infrastructure formed by robot-to-cloud communications. The design trade-off for SCMR is between the computation energy for the robot execution and the offloading energy for the cloud execution. The SCMR framework uses Web Sockets protocol for communication

between the individual robots and the cloud server. In case of cloud disconnection a virtual ad hoc cloud is created between the individual robots and the robot leader and the individual robots communicate with one another through the gossip protocol [24].

Distributed Agents with Collective Intelligence (DAvinCi) is a software framework that provides the scalability and parallelism advantages of cloud computing for service robots in large environments. It is implemented as a system around the Hadoop cluster with ROS as the messaging framework [25].

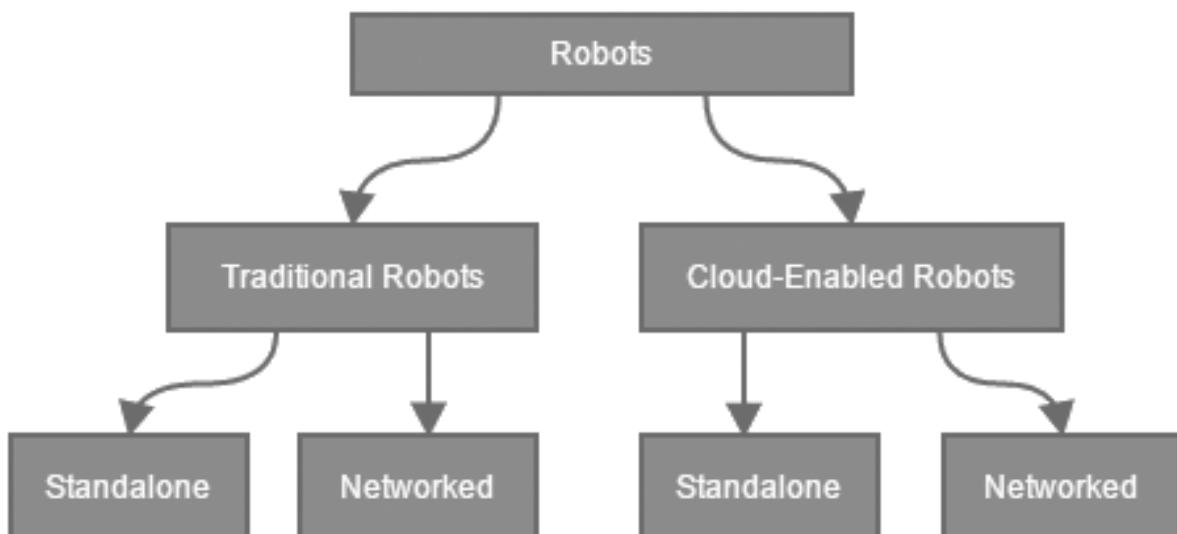
## CLOUD-ENABLED ROBOTS

Robots have some constraints in terms of computational capacity, memory and storage. CR help them to overcome these challenges. Opportunity to use cloud allows cost effective robots to be produced. Robots can be classified as traditional robots and cloud-enabled robots. This paper focuses on cloud-enabled robots. Cloud technologies not only empower robots but also it allows them to network each other regardless of distance. Cloud-enabled robots are divided into two categories as standalone robots and networked robots. Classification of robots is shown in Figure 2.

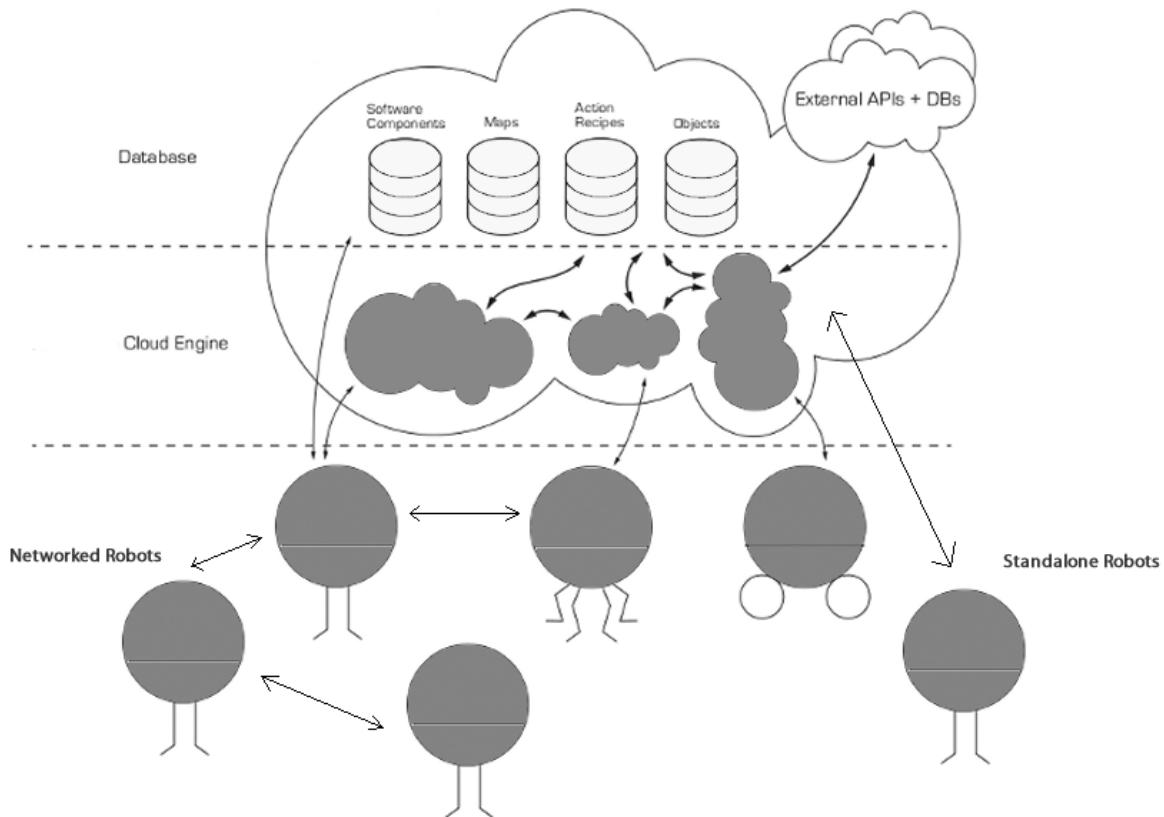
Robots can do a wide variety of works such as grasping, identifying objects, SLAM, monitoring, networking and some other actuating works. Robots can grasp formerly known objects easily. They can also grasp novel objects with the help of cloud. In [26], a study about grasp planning in the presence of shape uncertainty and how cloud computing can facilitate parallel Monte Carlo sampling is presented. Kehoe et al focus on parallel-jaw push grasping for the class of parts that can be modelled as extruded 2-D polygons with statistical tolerances.

Standalone robots can benefit from cloud in terms of computation power, storage capacity and memory. However, networked robots can make networks, share their information through cloud and can perform collaborative works. CR infrastructure with standalone robots and networked robots is presented in Figure 3.

SLAM [27] refers to a technique for a robot or an autonomous vehicle to build a map of the environment without a priori knowledge, and to simultaneously localize itself in the unknown environment. SLAM is important in robotics and there are plenty of researches. It consists of statistical techniques such as Kalman filters, mapping and sensing. Riazuelo et al develop a



**Figure 2.** Classification of Robots.



**Figure 3.** Standalone and Networked Robots.

cloud framework which name is Cloud framework for Cooperative Tracking and Mapping (C2TAM) [28]. This is a visual SLAM system based a distributed framework where the CPU-intensive map optimization and storage is allocated as a service in the Cloud, while a light camera runs on robots for tracking. The robots need only internet connection for tracking and cooperative relocating. C2TAM provides a database consisting maps can be built and stored, stored maps can be reused by other robots. A robot can fuse its map online with a map already in the database, and several robots can estimate individual maps and fuse them together if an overlap is detected.

Virtual monitoring technology has been applied in more and more fields such as military, education, medical science, manufacturing engineering, and so forth. In order to realize resource sharing among all collaborating robots in a virtual monitoring system, cloud computing is proposed by combining professional computing equipment as a super virtual computing centre. Zhang et al. proposed 3D virtual monitoring system based on CR. This system's architecture consists of communication language for agent communication, algorithm for cooperative working and conflict resolution. Prototype system is applied for the monitoring of fully mechanized coal-mining equipment [29].

Networking robots overcome the limitations of stand-alone robots by having robots, environment sensors, and humans communicate and cooperate through a network. Mateo et al, presented a work to decrease message overhead occurred because of communication. The proposed an information sharing model for group communication based on Brownian agent approach. In presented work they grouped robots in clusters with a cluster head to overcome message overhead [30]. Kamei et al, proposed prototype infrastructure of cloud networked robotics enables multi-location robotic services for life support [31-34]. Their study focuses on requirements in typical daily supporting services through example scenarios that target senior citizens and the disabled.

## CONCLUSIONS

This article presents cloud computing, cloud robotics and cloud interaction of robots. It surveys cloud platforms and cloud-enabled robotics studies. Standalone robots can benefit cloud technologies and networked robots can perform collaborative works. Networked cloud-enabled robots can share computation resources, information and data with each other and can access new knowledge and skills not learned by themselves. This is a new paradigm in robotics that we believe leads to exciting future developments. Future works can focus on reliable connection, data offloading methods and ubiquitous networking among robots and cloud services.

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## **ROBOTSKE PLATFORME U METODI OBLAKA**

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### **SAŽETAK**

Robotika u metodi oblaka područje je ubrzanog razvoja koje omogućava da roboti proslijede procesorski i memorijski zahtjevne poslove u računalni oblak. Roboti su ograničeni u procesorskom kapacitetu, radnoj memoriji i mogućnostima pohrane podataka. Oblak omogućava praktički neograničenu procesorsku snagu, memoriju, mogućnost pohrane i posebno mogućnosti kolaboracije. Roboti u oblaku dijele se u dvije kategorije kao samostalni i umreženi roboti. Ovaj rad opisuje robotske platforme u metodi oblaka, samostalne i umrežene robotske procese poput prihvata, istovremene lokalizacije i mapiranja te promatranja

### **KLJUČNE RIJEČI**

oblak, robotika u metodi oblaka, računanje u oblaku, platforma oblaka, umreženi roboti

# CONCEPTS OF THE INTERNET OF THINGS FROM THE ASPECT OF THE AUTONOMOUS MOBILE ROBOTS

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## ABSTRACT

The Internet of Things (IoT) is slowly gaining grounds and through the properties of barcodes, QR codes, RFID, active sensors and IPv6, objects are fitted with some form of readability and traceability. People are becoming part of digital global network driven by personal interests. The feeling being part of a community and the constant drive of getting connected from real life finds its continuation in digital networks. This article investigates the concepts of the internet of things from the aspect of the autonomous mobile robots with an overview of the performances of the currently available database systems.

## KEY WORDS

IoT, mobile robotics, DBMS performance, cloud computing, wireless sensor networks

## CLASSIFICATION

ACM: D.1.1.  
JEL: Z19

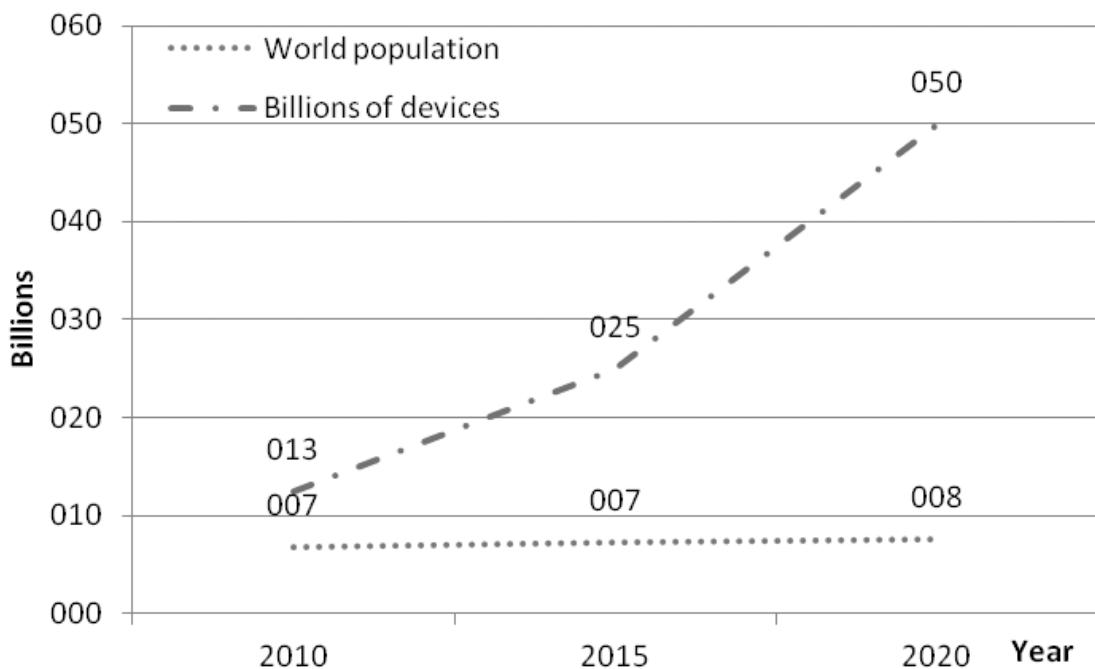
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## INTRODUCTION

Information and communication technology has started on large computers called the main frame of the 1960s, the 1970s minicomputer was a practical solution, workstation appeared with the development of the microprocessor in the 1980s, and personal computers became popular in the 1990s. This progress is largely accelerated due to the development of a semiconductor integrated circuit technology [1]. As a result, the computer and the network cost, made a remarkable progress in terms of performance, have infiltrated and became embedded into the society at large scale. In a network, stemming from the Internet to research of ARPANET, by the 1990s WWW (World Wide Web), showed the explosive spread. In the background, it may become capable of high-speed large-capacity communication by development of optical communication technology. From the wireless communication technology, to the spread of mobile phones and high-speed wireless LAN, all the equipment leads to the era of the global network. Dramatic improvement in communication speed, and to underpin the transition from e-mail to the video content, the fusion of communication and broadcasting has begun and started an expansion of the IoT devices as shown in Figure 1.

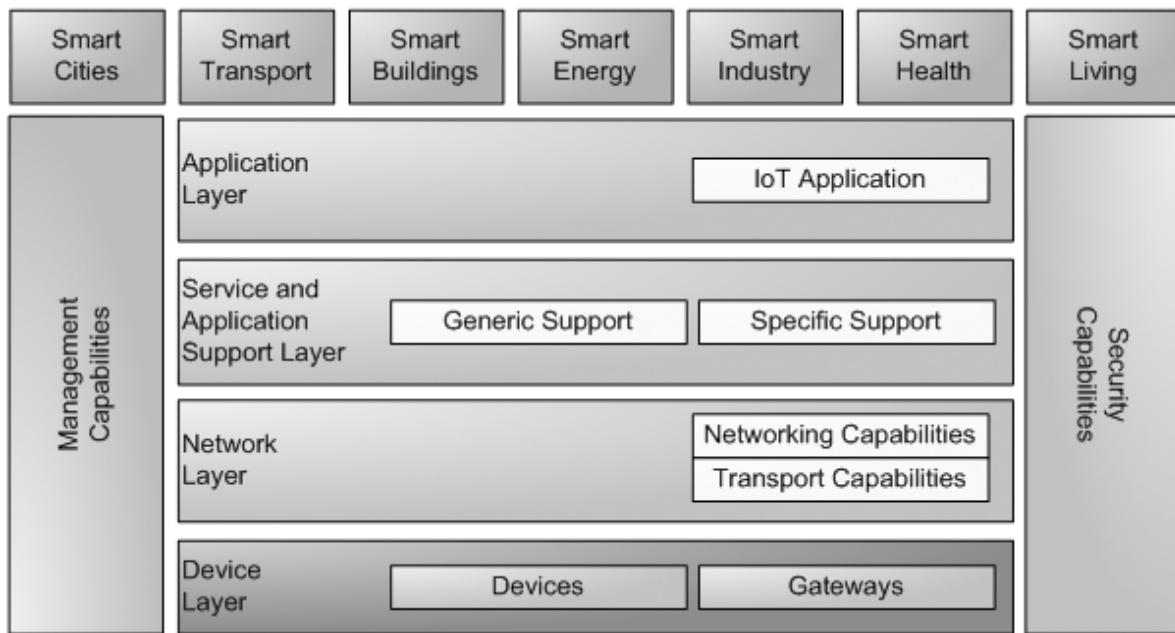
## INTERNET OF THINGS

The Internet of Things is not a single standalone technology, It is a concept in which most new things are connected and enabled such as street lights being networked and things like embedded sensors, image recognition functionality, augmented reality, near field communication are integrated into situational decision support, asset management and new services [2]. These bring many business opportunities and add to the complexity of IT.



**Figure 1.** IoT devices and the future evolution.

The Internet of Things offers solutions based on the integration of information technology, which refers to hardware and software used to store, retrieve, and process data and communications technology which comprises electronic systems used for communication between individuals or groups [3]. The rapid convergence of information and communications technology is occurring at many layers of technology innovation (Fig. 2): the cloud, data and communication pipes/networks and device.



**Figure 2.** IoT Layered Architecture.

The potential market for wireless communication technology is one of the rapidly-spreading segments in the industry of integrated circuits. Breathtakingly fast innovation, fast changes in communications standards, the entry of new players, and the evolution of new market sub segments will lead to disruptions (disorder, confusion) across the industry [4].

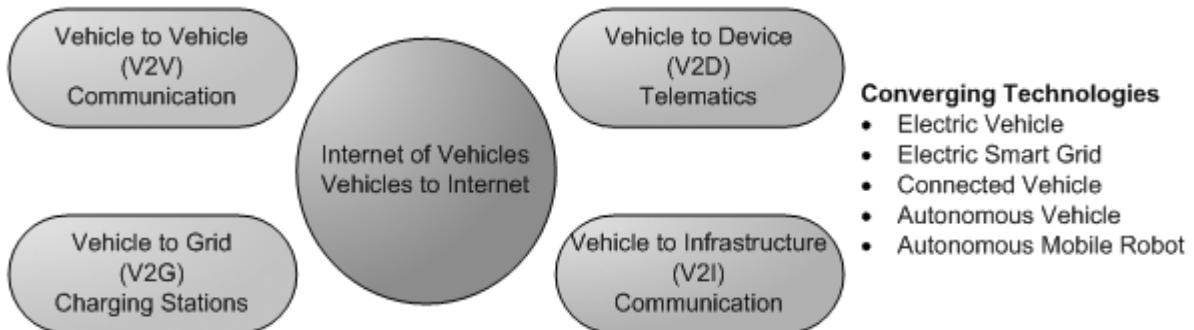
## IOT AND AUTOMOMOUS MOBILE ROBOTS

The connection of vehicles or mobile robots to the Internet brings about a wealth of new possibilities and applications which bring new functionalities to the individuals and/or the making of transport easier and safer. In this context the concept of Internet of Vehicles (IoV) connected with the concept of Internet of Energy (IoE) represent future trends for smart transportation and mobility applications as depicted (described, shown, illustrated) in Figure 3 [5].

Self-driving vehicles today are in the prototype phase and the idea is becoming just another technology on the computing industry's parts list. Using automotive vision chips that can be used to help vehicles understand the environment around them by detecting pedestrians, traffic lights, collisions, drowsy drivers, and road lane markings [6]. Those tasks initially are more the sort of thing that would help a driver in unusual circumstances rather than take over full time.

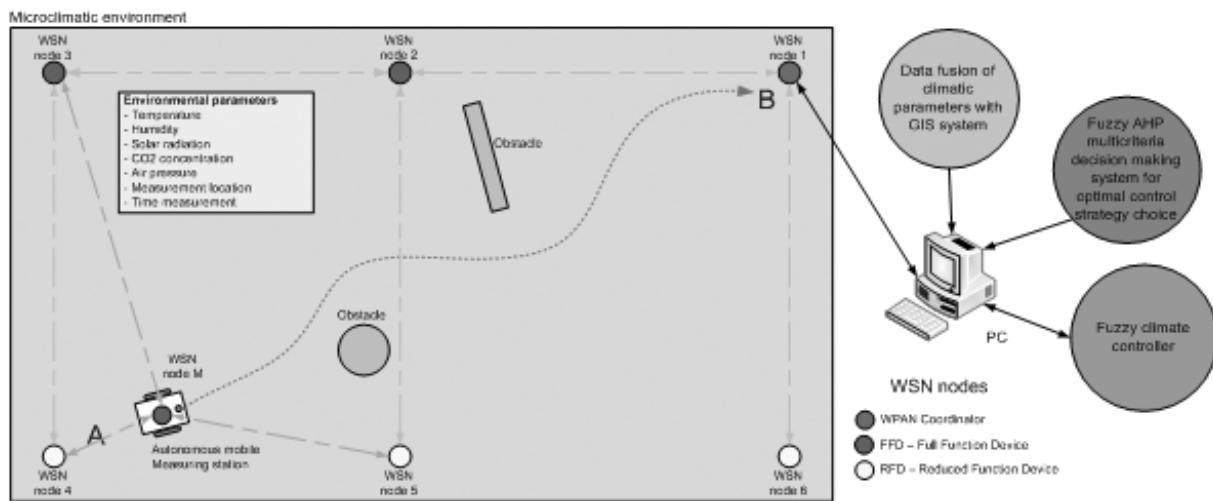
## MICROCLIMATIC CONTROL USING IOT

Control of the microclimate is achieved through collecting parameters with the help of a



**Figure 3.** Converging Technologies.

mobile measuring station, preparing, processing data and performing control activities making possible to reach the desired goals as illustrated in Figure 4. After processing, the control system provides information about the operation of the system and sends control signals to the actuator. The executive element takes over the energy from the auxiliary electrical source and proportionally to the control signal adapts the flow of matter and/or energy on the control input [7]. The sensor network is a divided system which makes the sensor field of various types mutually connected with a communication network [11]. The sensor network consists of individual multifunctional sensor nodes [10].



**Figure 4.** Structure of the controlled microclimatic environment.

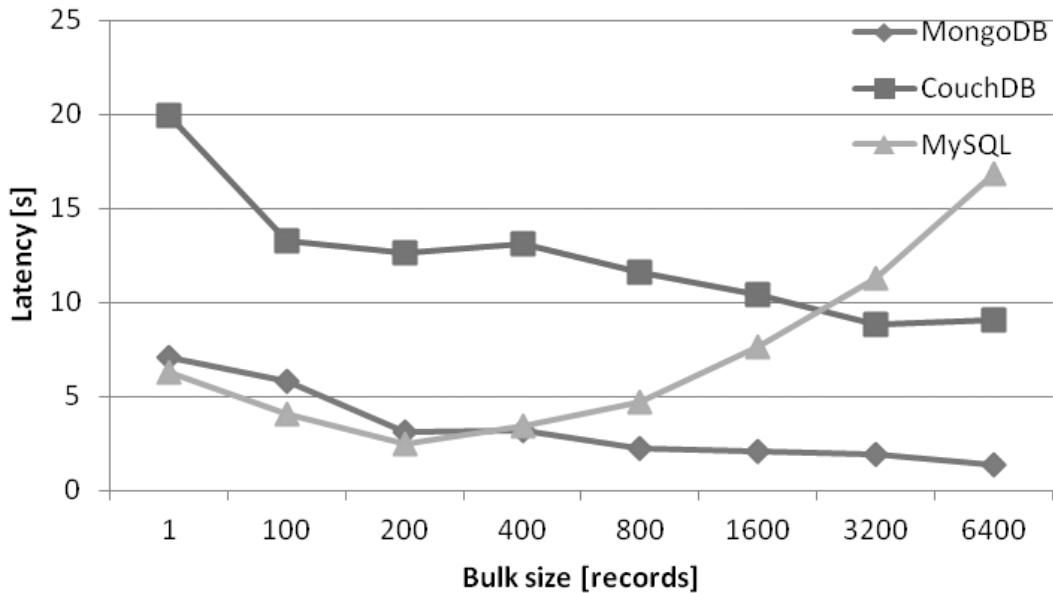
In most cases the nodes connect wirelessly into a communication network, thus forming a Wireless Sensor Network – WSN. The WSN consists of battery-powered modules, which, in fact, represent sensor nodes [8]. The basic surface of the experimental model of the microclimate environment is 15,33 m<sup>2</sup>. The model is built for experimental purposes and it is situated in the yard of Subotica Tech – College of Applied Studies in Subotica, Serbia. In order to use the microclimatic environment effectively throughout the year under Central-European climatic conditions it is necessary to heat the greenhouse in winter, and cool it in summer. Such a system should be automated as much as possible [9]. Microclimate control in greenhouses is a responsible and complex process because there are many factors which influence the climate, which are interdependent. In order to achieve the goal of the highest possible crop on the given plot while maintaining appropriate product quality, it is necessary to provide suitable microclimatic conditions, while ensuring that this goal is achieved by consuming the least possible quantity of energy [11].

## CONTROL DATA STORAGE TO THE CLOUD

By its name, a cloud database is a database that runs on a cloud computing platform, such as MS Onedrive, Dropbox and Google drive. The cloud platform can provide databases as a specialized service, or provide virtual machines to deploy any databases on. Cloud databases could be either relational or non-relational databases. Compared to local databases, cloud databases guarantee higher scalability as well as availability and stability [16]. Thanks to the elasticity of cloud computing, hardware and software resources can be added to and removed from the cloud without much effort. Users only need to pay for the consumed resource while the expenses for physical servers, networking equipments, infrastructure maintenance and administration are shared among clients, thus reducing the overall cost. Additionally, database service is normally provided along with automated features such as backup and recovery, failover, on-the-go scaling, and load balancing.

Cloud computing has been established as one of the major building blocks of the Internet of Things [17]. New technology enablers have progressively fostered virtualisation at different levels and have allowed the various paradigms known as “Applications as a Service”, “Platforms as a Service” and “Infrastructure and Networks as a Service”. As part of this convergence, IoT applications such as sensor-based services will be delivered on-demand through a cloud environment. This extends beyond the need to virtualize sensor data stores in a scalable fashion. It asks for virtualization of Internet-connected objects and their ability to become incorporated into on-demand services such as Sensing-as-a-Service. Figure 5 shows the performances of tested database management systems.

The choice of the databases was based on the fact that those were among the most popular databases available, and that they were the representatives for their kinds. Many large organizations have been using them in production, such as Facebook, Google, Wikipedia, LinkedIn, Instagram, etc. On the other hand, each database has its own promising strength that is worth exploring. MySQL so far has been the most popular open source SQL database. MongoDB was built to work with very large sets of data [17]. CouchDB has its user-friendly RESTful API. Meanwhile, Redis is said to be very fast thanks to its in-memory storage. Redis is an open source, BSD licensed, advanced key-value cache and store system. With the bulk data, the MongoDB has the smallest latency, but the overall best score goes to MySQL.



**Figure 5.** Bulk insert latency test with various DBMS.

## CONCLUSIONS

The concept of Internet of Vehicles (IoV) is the next step for future smart transportation and mobility applications and requires creating new mobile ecosystems based on trust, security and convenience to mobile/contactless services and transportation applications in order to ensure security, mobility and convenience to consumer-centric transactions and services. This requires robust sensors and actuators which are able to reliably deliver information to the systems mentioned above. Such reliable communication needs to be based on M2M communication protocols which consider the timing, safety, and security constraints.

The vision of the future Internet of Things is setting new challenges and opportunities for data management and analysis technology. Gigabytes of data are generated everyday by millions of sensors, actuators, RFID tags, and other devices. As the volume of data is growing dramatically, so is the demand for performance enhancement. When it comes to this

Big Data problem, much attention has been paid to cloud computing and virtualization for their unlimited resource capacity, flexible resource allocation and management, and distributed processing ability that promise high scalability and availability.

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## KONCEPTI INTERNETA STVARI S GLEDIŠTA AUTONOMNIH MOBILNIH ROBOSTA

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### SAŽETAK

Internet stvari (eng. *Internet of Things – IoT*) polako uzima zamah u vidu nove paradigme i kroz svojstva barkodova, QR kodova, RFID, aktivnih senzora i IPv6 protokola, fizički objekti su opremljeni s nekim oblikom čitljivosti i praćenja. Ljudi postaju dio globalne digitalne mreže kojim upravljaju osobnim interesima, potrebama i željama. Osjećaj pripadnosti zajednici i nagon povezanosti s stvarnim životom pronalazi nastavak u digitalnim mrežama. U radu se istražuju koncepti interneta stvari iz aspekta autonomnih mobilnih robota s osvrtom na performanse trenutno dostupnih sustava za upravljanje bazama podataka.

### KLJUČNE RIJEČI

IoT, mobilna robotika, performanse SUBP, računarstvo u oblaku, bežične senzorske mreže

# MOTION CONTROL OF WHEELED MOBILE ROBOTS

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Regular article

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## ABSTRACT

This article presents strategy for navigation of a wheeled mobile robot in unstructured environments with obstacles. The vehicle has two wheels independently to control the angular velocity. This work deals with mobile robots modelling then control strategies and simulation results. Simulation results recommends fuzzy logic controller for the wheeled mobile robot motion in unstructured environments.

## KEY WORDS

intelligent wheeled mobile robot, motion control, unknown and unstructured environments, obstacles, fuzzy control strategy

## CLASSIFICATION

ACM: D.1.1.

JEL: Z19

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## INTRODUCTION

Nowadays, there has been a growing interest in control of motion robot in an unstructured environment [1]. In this subject there are a lot of works and applications. For instance, NASA is using mobile robots to explore Mars surface [2]. Unstructured environment may have some obstacles. For this reason, wheeled mobile robots must be able to detect the environment. For this, ultrasonic sensors and a stereovision system should be around the vehicle to provide control.

The technological stage of motion mechanisms, sensor devices allow pointing the researches to the development of control strategies to solve complex problems that the robot must deal with. When the vehicle moves towards the target detected an obstacle or slope, it is necessary an avoidance strategy. For effective operation of intelligent robots, they are equipped with system of perception of the environment and systems for situation analyzing and decision making, and they perform motion planning [3].

Fuzzy controller is proposed to the wheeled mobile robot motion in unstructured environments that including obstacles. Fuzzy reactive control is investigated for automatic navigation of an intelligent mobile robot. Fuzzy controller includes collision and obstacle avoidance between robots. Navigation control of the robot is realized through fuzzy coordination of all the rules. Three simple navigation strategy: seek-goal, traverse-terrain, and avoid obstacles [1-5].

This paper presents a how to control of motion and velocity of vehicle in an unstructured environment that contains obstacles with using ultrasonic sensors and a stereovision system.

The article is organized as follows:

- Section 1: Introduction.
- Section 2: Mobile robots modelling.
- Section 3: Control strategy for mobile robots.
- Section 4: Simulation results.
- Section 5: Conclusion.

## MOBILE ROBOT'S MODELLING

The mobile robot has two driving wheels fixed. The two fixed wheels are controlled independently by motors. The robot consists basically of ultrasonic sensors in the front, to the right and to the left of the vehicle [1]. The wheels are controlled on velocity and sense of turning. The sensors provide the distance data of possible obstacles in short range.

The resultant motion is described by the linear velocity  $v(t)$ , the direction  $q(t)$  and a rotational motion (rotational velocity)  $w(t)$ .

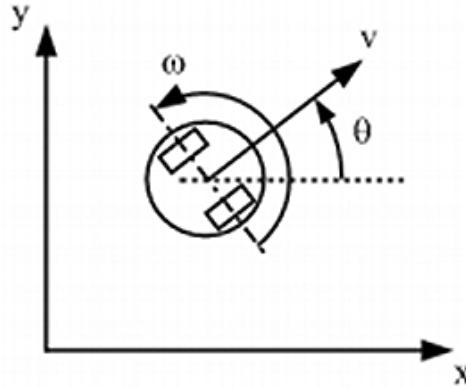
Kinematics model for wheeled mobile robots; there are two identical castors of the mobile robot. There is no transitional slip between the wheels and the surface. Here is enough rotational friction between the wheel and the surface; so, the wheels can rotate without disturbance. For low rolling velocities this is a reasonable wheel moving model.

Suppose that the robot moves on a plane with linear velocity expressed in the local frame as  $v = [ V_x, V_y, 0 ]^T$  and rotates with an angular velocity vector  $\omega = [ 0 \ 0 \ \omega ]^T$ .

If  $q = [ X \ Y \ \theta ]^T$  is the state vector describing generalized coordinates of the robot (i.e., the COM position,  $X$  and  $Y$  and the orientation  $\theta$  of the local coordinate frame with respect to the inertial frame). The mobile robot's configuration is generally defined five variables. Such as:

$$q = [x, y, \theta, \varphi_r, \varphi_l]^T \quad (1)$$

where  $\theta$  is the orientation angle of the mobile robot,  $x$  and  $y$  are two coordinates,  $\varphi_r(t)$  and  $\varphi_l(t)$  the rotation angle of the right and left driving wheel, respectively [7]. This motion is shown in Figure 1.



**Figure 1.** Explanation of the robot motion.

## CONTROL STRATEGY FOR MOBILE ROBOTS

In this section contains the proposed control strategy for motion mobile robots. Fuzzy control is applied to the navigation of the autonomous mobile robot in unstructured environments with obstacles. The control scheme can be described as an open loop control law, where the input variables are previously defined and available under the format of a vector containing the discrete-time constant control values. These values are used to command the independent wheel velocities. This control law may, command the robot towards a physical obstacle. Therefore, the controller still must solve the problem of obstacle and workspace boundary avoidance. The robot must change its trajectory when it goes into a physical obstacle or a workspace boundary. When the robot depth sensors detect an obstacle approximation, it changes the direction of movement respecting the strategy described [11, 12].

Fuzzy logic controller used in mobile robot navigation is one of the proposed strategy. The approach is to extract a set of fuzzy rule set from a set of trajectories provided. For this purposes the input to all the fuzzy logic controller are left obstacle distance, right obstacle distance, front obstacle distance and target angle considered [13]. The fuzzy rules help the robots to avoid obstacles and find targets. At first, there are two simple behaviours:

- reach the target, and
- avoid the obstacles.

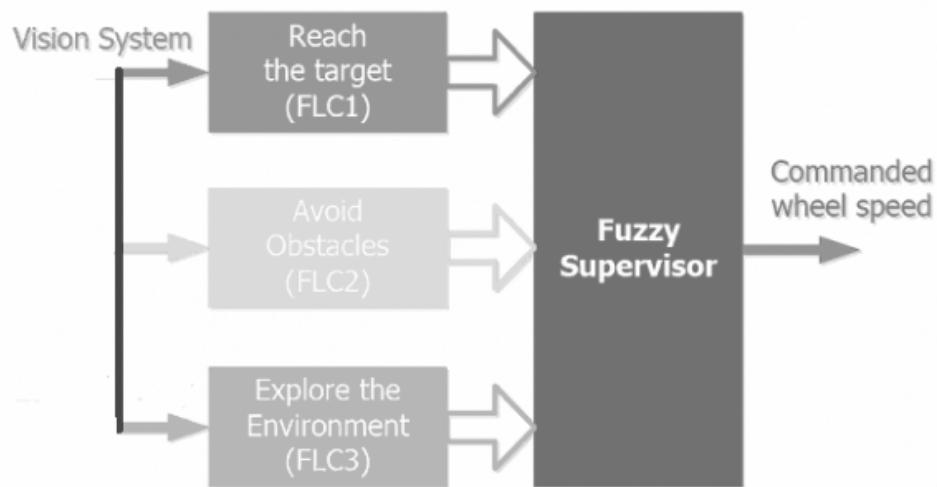
The reach the target behaviour as well as avoid obstacles behaviour depends on artificial vision information and is the primary task for the mobile robot [14]. It has the highest priority and takes place only if an obstacle appears on the robot path. These controllers are sufficient to guarantee satisfactory navigation performances for the mobile robot in most of the navigation tasks, [15-20]. The control structure in shown in Figure 2.

The fuzzy sets for the output variables of the wheel angular speed correction  $\Delta\omega = \omega_r - \omega_l$  (turn-right, zero and turn-left) of the mobile robot are shown in Figure 3.

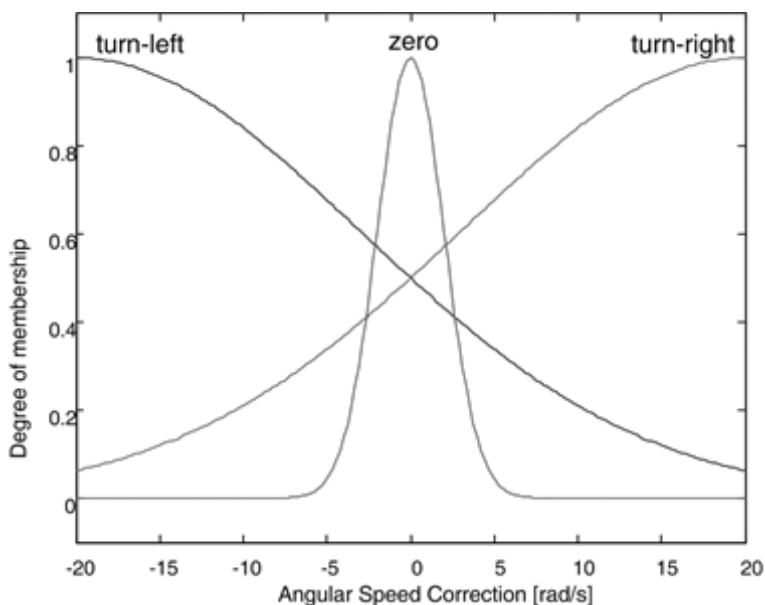
The output variables are normalized between:  $\Delta\omega \in [-20 \text{ rad/s}, 20 \text{ rad/s}]$ . The other output variable of the fuzzy controller is vehicle velocity. The output variables are normalized between so that velocity is in the interval  $[-10 \text{ m/s}, 20 \text{ m/s}]$ .

The fuzzy sets for the output variables – low and high velocity – are shown in Figure 4.

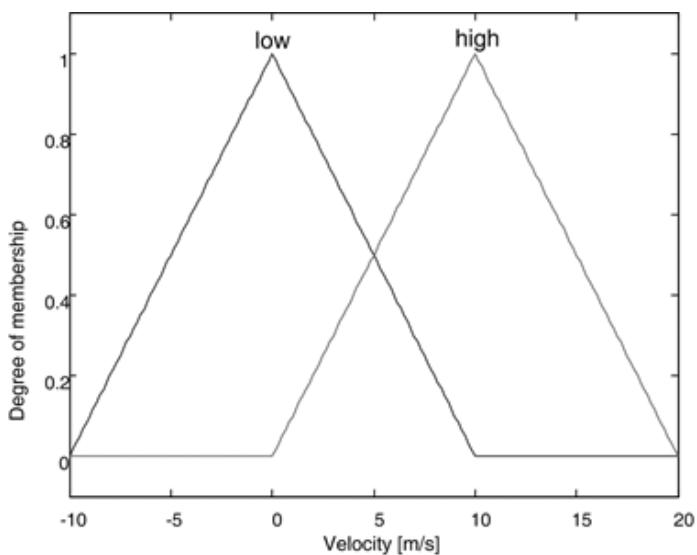
Fuzzy supervisor, in order to safely reach the target, a fuzzy supervisor determines the priority of execution for the three elementary behaviours [17, 18].



**Figure 2.** Diagram of the control structure.



**Figure 3.** Membership functions of the angular speed difference  $\Delta\omega$ .

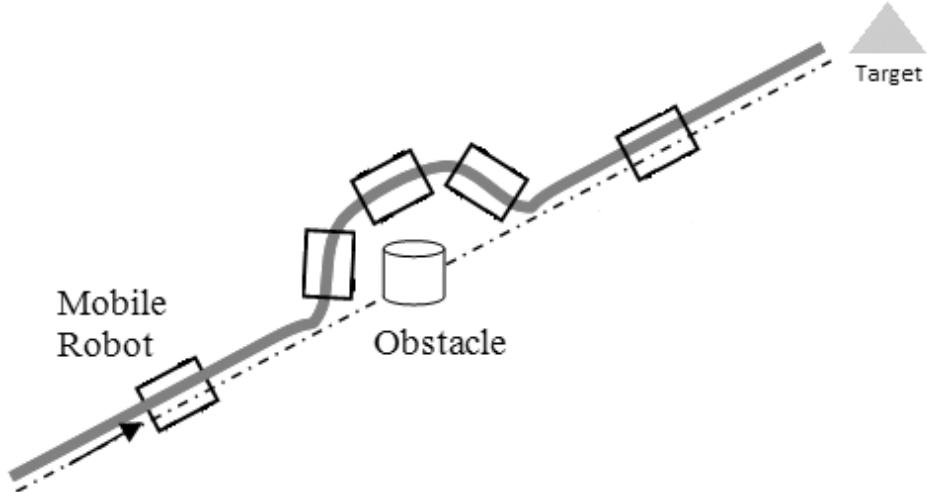


**Figure 4.** Membership functions of the velocity of the mobile robot.

## SIMULATION RESULTS

The control strategy was tested through simulations of robot motion. The motion command was provided by the two independent wheels velocities,  $w_l(t)$  (left wheel) and  $w_r(t)$  (right wheel), formatted on two vector of consecutive discrete-time instants of control application. Fuzzy control is advantageous in terms of avoiding obstacles and response times [21-25].

In particular, the navigation strategy proved to be extremely sensitive to the balance between avoid obstacle and reach the target behaviours. Simulation results are shown in Figure 5.



**Figure 5.** Obstacle avoidance trajectory of mobile robot.

## CONCLUSIONS

This article presents modeling, control strategies and simulation results of the motion of wheeled mobile robots. Kinematics model for wheeled mobile robots; there are two identical wheel of the mobile robot. Fuzzy logic strategy has a modular structure that can be extended very easily to incorporate new behaviours. Mobile robot navigation strategies using fuzzy logic have major advantages over analytical methods also simulation results recommends fuzzy logic controller for the wheeled mobile robot motion in unstructured environments (obstacle avoidance behaviour and velocity control of vehicle).

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## UPRAVLJANJE MOBILNIM ROBOTOM S KOTAČIMA

B. Kocaturk

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### SAŽETAK

U radu je opisana strategija navigacije mobilnog robota s kotačima u nestrukturiranoj okolini s preprekama. Za Vozilo ima dva neovisna kotača za upravljanje kutnom brzinom. Rad modelira mobilne robote s kotačima, zatim navodi strategije upravljanja i rezultate simulacije. Rezultati simulacije upućuju na korištenje upravljačkih jedinica s neizrazitom logikom, u slučaju mobilnih robota s kotačima u nestrukturiranim okolinama.

### KLJUČNE RIJEĆI

inteligentni mobilni robot s kotačima, upravljanje gibanjem, nepoznata i nestrukturirana okolina, prepreke, strategija neizrazitog upravljanja

# REQUIREMENTS OF THE INSTALLATION OF THE CRITICAL INFORMATIONAL INFRASTRUCTURE AND ITS MANAGEMENT

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## ABSTRACT

The segments of the network can be paralysed by a series of chance events or a well-organized, targeted attack. If we know our system and lead a safety-conscious life we can avoid unpleasant events, system down. The Critical Information Infrastructures has become a complex network. Consequently the items of the system, their mutual effects and links and the map of the network have to be known properly. We have to realize that everything is linked with each other and the physical and logistical networks have mutual effects on each other as well. It is obvious, that the problem of mapping the complexity is very important. One of the most important part of the cognition is the obtainment and sorting of information.

## KEY WORDS

network, structure of networks, critical infrastructures, critical information infrastructures

## CLASSIFICATION

JEL: L86, M15

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## **INTRODUCTION**

The main goal of my essay is to highlight the importance of system thinking and the complexity of the critical informational infrastructure. In the followings we introduce the complex structure of a datacentre, its aspects, and the highly combined system of its elements.

Among the system elements the essay is introducing the sophisticated structure of a datacentre in details, while outlining the informatics hardware, software and other technologies. Relating regulations, financial and human resources factors, as important substances, are also mentioned.

According to the basic principle of the system thinking the certain system cannot be examined as an independent unit. Each individual system consists of different networks, while the systems are creating other networks with each other as well. The elements of the networks are permanently influencing each other and continuously altering themselves. The critical informational infrastructure can be considered such a system as well, which is continuously changing from its development till its shutdown. The IT systems are not developed exclusively for their own sole purposes, but they are based on the strategy of the organisation created in line with the main goals of the business venture/organisation. The informatics strategy is usually created simultaneously with the other strategies of the organisation and it supports the critical informational infrastructure. Any other course of development can result in unexpected and serious errors. The hierarchical structure and system thinking are inevitable factors of the critical informational infrastructure management. The IT systems can be influenced by different stochastic impacts. If the management is not concentrated in one hand only “symptomatic treatment” can be applied, which similarly to the medical disciplines cannot solve the problem. Moreover the intervention to unknown system elements can cause damages as well. The IT system is composed by the relating processes and the network structure of different stages and their modifications monitored in various time spans of its running [1].

The critical informational infrastructure can be described by the following five criterions:

- main management procedures (central management and coordination),
- information security,
- domino theory<sup>1</sup>,
- the principles of the weakest chain-link and the particle-whole,
- interdependency<sup>2</sup> [2].

The democracy approaching to anarchy, the network of Internet, the connection of cells is all scale free networks, which can withstand the random attacks. Nevertheless they do not satisfy the demands of the critical informational infrastructures, because they are quite unprotected against targeted attacks. The structure of armies has also not evolved accidentally on a way as we know it today. Nowadays all armies based on hierarchical, centralised authoritarian systems, which include not only the human resources but the technical regulations and their relations composing the structure as a whole. Business ventures often outsource their management, which can be motivated by economic reasons emerging during financial crisis situations. However certain outsourced functions or the concentration of same working phases in one country can pose serious threats on a long term. They can be advantageous from financial aspects but in case of social or national security viewpoints they can be very harmful. Is it satisfactory if all client databases of a business venture active in different countries are stored in one state, or our bank saves certain data or business procedures in cloud applications? The answer is obviously: no. An integrated IT system developed in line with the principles of system thinking is essential in the life of a country or an organisation.

The requirements regarding the availability, level of data management, archives and savings etc. have to be determined by the management of the organisation. Following this phase the conditions of development and running have to be set up. These conditions are as follows:

- financial resources (during the whole life cycle);
- human resources (skilled experts, logically organized hierarchical structure of personnel);
- legislation and the determination of working procedures;
- timing (technological sequence and time factors).

The efficiency of the system will be defined by the weakest of the aforementioned factors. The conditions, environment and impacts are altering dynamically. The failing of certain elements can be balanced moderately by the enhancement of the others but the safety of the system can be ensured by the homogeneity.

According to this statement and the COBIT<sup>3</sup>, our system can be ranked into four evolvement level. The highlighted characteristics of the primary and service continuity model are as follows (the list is not exhaustive):

- 0 Non-existing** – There are no recognizable processes at all. By the general consideration, the management does not have to deal with the continuity of service.
- 1 Initial/Ad Hoc** – There are signs of the recognition of an activity, which has to be coped with. However there are no standardized processes but ad hoc actions are applied in case of individual incidents. The procedures of general management are irregular, the responsibilities for the continuous service are informal and the authorizations for the tasks to be carried out are restricted. The management gradually recognizes the risks threatening the continuous services and the need of it. The IT responses to significant shutdowns are slow and unprepared.
- 2 Periodic, but instinctive** – The processes reach the level of similar actions carried out by different employees involved in similar processes. The responsibility for the continuous service is determined. The inventory of critical systems and elements exists but it can be unreliable. The evolvement of the procedure of continuous service is in progress but its success depends on the individuals.
- 3 Regulated process** – The basic processes are standardized and documented and they are introduced in trainings. The programme of the training is formulated but the implementation of it is initiated by individually. The responsibilities for planning and testing of the continuous service are determined and assigned to certain persons. Based on individual initiations the regulations are followed and trainings are implemented in order to manage serious extraordinary situations or catastrophes. In case of highly available components and systems redundancy measures are applied. The inventory of critical systems and components is updated.
- 4 Controlled and measurable** – The management monitors and measures the appropriateness to procedures and intervenes in case of improper running. The leader informational and decision making support systems utilize the provided information. The regulations and responsibilities regarding the continuous service are forced to be carried out. The extraordinary events disrupting the continuous service are classified and all relating chains of reporting are known by all concerned persons.
- 5 Optimized** – The informatics system is used for the automatization of working processes on an integrated way and other tools are provided in order to improve the quality and efficiency. The informatics and continuous operation plans are integrated into the business activity plans and they are regularly updated. The procedures of availability and the planning of continuous service are completely in harmony. The management excludes any sources of catastrophes or serious emergency situations. The goals achieved by the continuous service are regularly measured and its metrics are calibrated [3, 4].

Nowadays that facility or service, which despite of its importance in case of its malfunction, disturbance, failing or destruction do not cause direct, serious damages to the economic, social, healthcare, public or national security situation of the population or the working of public administration, is also called critical infrastructure [5]. Actually the real grave problem is not the false declaration of a non-essential system as an essential one, but the neglect of the real primary systems to another less important resources.

The development of the IT system suitable for the goals of the business venture or the critical infrastructure can be initiated if the four basic principles and the commitment of the management are provided. The main element of the system is the central database, which can be handled as an integrated system virtually, but according to the principles of geo-redundancy must be established in at least two or more locations. If the whole infrastructure is considered as one system, the database is one of the system elements and the part of the complex network. In the following part only this element is going to be examined by its connections and non-exclusive nature in the system.

The geographical location of the system elements cannot be neglected. The climate, structure of the soil, geographical location also can influence the operation of our system. Besides of them the economic, political and security aspects have to be objectively determined as well. Prior to the establishment of the facility the distance of its location from any settlement, the density of population, the standard of living and the traffic conditions have to be well considered. The typical statistical information such as the probability of earthquakes, floods, fires, storms (tornados, hurricanes), temperature, number of sunny hours, snow, height above the sea or ground level etc. regarding the particular area are also very important. The geographical environment has also its impact on the organization of the physical, electronic and human protection of the facility. The stability and reliability of the means of communication, the capability and the possibility of separated operation of other public services (water, electricity, gas and other services) have to be examined as well. The conditions of the lines of communication (logistic), their load-bearing capacities and the risks of extreme weather conditions are also very important. At last but not least the relating environmental protection aspects have also to be considered.

Following the obtainment of the aforementioned information the main characteristics of the datacentre have to be determined. According to the TIER recommendations of the Uptime Institute the datacentres can be ranked into four groups in which the weakest chain-link has to be examined, Table 1.

The datacentre's main parts are the informatics and communication infrastructures, which include the server and machine halls (server rooms), encrypting rooms, incoming communication room (receiver), info-communication halls, technical (they can be separated, e.g. UPS<sup>4</sup>, air conditioning, firefighter etc.) rooms, stores, workshops, control rooms, aisles and other premises. During the construction the materials and thickness of the walls, the weight-carrying capacities of the roofing and flooring, the waterproofing, sizes and security characteristics of the doors and windows, the EMC<sup>5</sup> characteristics of electromagnetic protection, the foundations of the houses have to be planned properly. The ground-plan of the premises, structure of the soil, the underground water sources, the orientation of the building, its distance from other constructions, the condition of roads, the possible environmental effects, the names of rooms surrounding the main functional halls, the overall condition of the building have to be documented.

During the construction the regarding standards, legislation, security regulations of operation and utilization, work and healthcare rules have to be followed strictly, besides the suitability

**Table 1.** TIER recommendation of UPtime. TIER I – basic infrastructure, one way energy supply without redundancy, TIER II – certain elements of the infrastructure have reserves, TIER III – the infrastructure can be maintained without shutdown, and TIER IV – fault-tolerant infrastructure [6].

Characteristics	TIER I	TIER II	TIER III	TIER IV
Active support elements	$N$	$N + 1$	$N + 1$	$2(N + 1)$
Supply route	only 1	only 1	1 active, 1 reserve	2 active
Maintained without service	no	no	yes	yes
Fault-tolerant	no	no	no	yes
Independent supply routes	no	no	no	yes
Permanent cooling	Depending on workload	Depending on workload	Depending on workload	Provided
Nominal capacity, W/m <sup>2</sup>	210 - 320	430 - 540	1070 - 1610	> 1610
Duration of construction, month	3	6	10 - 20	15 - 20
Annual shutdown, h	28,8	22	1,6	0,4
Availability of machine room, %	99,671	99,749	99,982	99,995

of construction jobs and utilization as a computer centre. The different execution plans cannot contradict to each other, which can be achieved by the means of continuous communication and cooperation. The cooperation of different professions is very important in the planning phase as well, because only this kind of joint activity can guarantee the high quality outputs in the fields of the construction of premises, cooling, mechanical engineering and informatics systems. Similarly to any other fields, the documentation of every phase of the construction is very important. According to this principle, apart from the basic documentation of the datacentre, the other descriptions of the water, sewer, air conditioning, fire protection and security systems have to be prepared. In order to satisfy the regulations and for the better guidance and crisis management the elements of the system have to have clear inscriptions on them.

In case of the installed hardware and software elements the compatibility must be fully proper. During the installation period the subcontractors have to certify that the selected equipment fulfils the relating demands and standards. Beneath the antistatic ( $10^{-9}$  -  $10^{-12} \Omega$  surface conductivity) flooring, the separated strong- and light-current, cooling and fire protection cables have to be placed and the floor covering has to satisfy the electric shock protection regulations ( $10^{-6}$  -  $10^{-9} \Omega$  surface conductivity). The static capacity of the foundation has to bear the weight of all the installations. The flooring cannot slope at all, except the logistic supply routes in which case a maximum 10 % slope angle is allowed by the correction of ramps. The load-bearing capacity of the logistic supply routes have to be adjusted to the heaviest installation to be carried on them.

The technological area, which is above the suspended ceiling, has to accommodate the cables of the sensors, fire protection and air conditioning devices. The floor, ceiling and walls have to be covered with dustproof, non-mouldering and fire resistant materials. The distance between the floor and ceiling must be minimum 2,5 m. The walls, floor and roof of the server hall must be equal to the load-bearing capacity of a 30 cm thick, solid brick wall. Because of security and heat protection reasons the installation of windows is not recommended. The size of the main doors must fit to the specified dimensions of the logistical supply routes and they have to withstand to any breakthrough attempts for minimum 15 min. The building structure has to satisfy the demands of waterproofing properly. The datacentre, including the structures of the public services, has to be protected against the dampness of the soil. In the

different rooms only the essential public service networks can be installed. In the walls, floor and ceiling of the datacentre no cables can be installed. If the aforementioned cables are installed above the protected rooms they must be divided and equipped with pressure sensors and automatic closing valves. The protected rooms must be equipped with dampness sensors and they must be protected against external water floods (e.g. fire extinguishing).

The rooms must be heated with water-free devices, for example with hot air. The air conditioning must be provided by industrial precision equipment, which is capable to run  $7 \times 24$  h. Due to the high demands the air conditioning equipment must be calibrated by  $2N$  cooling availability. In case of the failing of an element the system has to cool down the heat produced by the critical overload without the assistance of the air conditioning control system. For the operation of the equipment  $(22 \pm 1)$  °C temperature has to be provided by uninterrupted and filtered air and draught-free airflow, which also makes the room suitable for permanent working. The best way to achieve the goal and most effective work is to build a closed, cold corridor between the rack boots. The cold and warm conveying pipes of the corridors cannot hinder the operation of the systems and they cannot produce condensing water. In the cold corridor the temperature must be  $(22 \pm 1)$  °C, the level of relative humidity must be  $(50 \pm 10)$  % during peak hours as well. Based on the gathered statistical information the environmental and climate effects of the last 100 years can be determined by which, together with the characteristic data of the planned equipment and the given cubic metre of air, the cooling parameters can be planned. The unexpected breakdown of air conditioning has to be detected in real time and an alert message should be sent simultaneously. The noise pollution cannot exceed the standards. The deleterious effects of the mechanical equipment (e. g. diesel generator, air conditioning etc.) placed in the server room has to be reduced by isolations absorbing or reflecting the electronic radiation, while the vibration has to be handled by damping solutions. Due to the high level availability, similarly to the other redundant supply systems, the electrical systems need to have two separated supply tracks in cases of the external service provider and the datacentre as well. Both supply tracks must be controlled by an automatic switch and the power supply cannot be interrupted by and unexpected malfunction or planned maintenance. To ensure the permanent and independent power supply a diesel-electronic equipment must be installed, which automatically starts and provides electricity in case of unexpected interruption. During the bridging period a high availability  $2N$  UPS has to be used. The power supply systems have to satisfy all power demands of all equipment responsible for the continuous service of the datacentre. The independent power supply of the critical equipment placed in the server room has to be provided through separated tracks and circuit breakers, while the power is received by the redundant power supply units of the certain equipment. The whole electrical power network has to comply with the regarding standards and legislation.

The entrance and the exit of the building must be secured by automatic security system using electronic card, PIN code or biometric identification. All entry and exit must be unavoidably documented, which is provided by such technical solutions like one-man barriers, gates supervised by security guards. If the datacentre is unmanned the alert system has to go live automatically. All moving have to be monitored by CCTV systems. The electronic security systems can be substituted by human guard personnel, who register all movements at the entry points. The job of the security guard is supported by the CCTV system by which the guard can check the alert messages and monitor and control the security zones, fences, corridors and service rooms and other external areas. With the CCTV system, security lighting must be used as well, which can serve as the lighting of the emergency routes and exits, too.

The electronic signal system, monitoring the security areas, service rooms, doors and windows, wall, floors and roofs, is also an important part of the security measures. The

protection must include the elements of the supporting infrastructure as well and the local alerts must directly notify the security guard. The alert systems must react to the intrusion attempts, smoke, fire, water and the alteration of the humidity level [7].

Since the server rooms and the other service rooms must be handled as separated fire protection zones. They must be equipped by separated alert and automatic fire extinguisher systems. The fire alert system must be a VESDA<sup>6</sup> or an equal aspirant equipment.

In case of fire the security system must alert the employees locally, notify the reaction force, provide ventilation and close the fire clack-valves of the air condition system, however the automatic fire extinguishing has to be controlled by humans. In case of a fire nearby the server room the structure of the walls has to prevent the increase of heat – during the cooling period as well – which must stay below 50 °C in the server room. The fire extinguisher cannot damage the informatics systems. Prior to the fire extinguishing the servers have to save automatically and shut down. The cables of the electric power supply system must be fire resistant.

For the management of the datacentre all documents needed for the safe and continuous operation must be prepared. The documentation must include all preventive, detecting, improving measures, which should be taken in order to ensure the long term and safe operation. The regarding, updated and detailed technical documentation of the whole system including the instructions concerning the operation and crisis management must be available by every concerned specialists. By the means of different trainings the quality level of the management can be increased. The equipment and its technical characteristics of the informatics system are very important part of the datacentre. Since the infrastructural network is built from these elements and they continuously influence each other, they have to be operated in a complex homogeneous system. This equipment include the support devices, client stations, data storages, saving systems, the network active devices, the rack boots, data storage medias, uninterruptible power supplies, generators, air conditioning and ventilation, public service networks, the noise and vibration characteristics of the devices, thunder protection, controlling, security and fire alert systems and their characteristics. Indirectly this category includes the tools of maintenance, spare parts and the documentation (instructions of operation and safety measures, guaranties, licenses, contracts etc.), which can be hard-copy versions or stored digitally. Besides the hardware the software needed for the operation of the system and business procedures is also has to be mentioned. This category includes operation systems, saving, communication (mail clients), antivirus software, firewall systems, endpoint protection, supervising, log gathering and analysing, cyphering and office applications or other business support products such as web applications, databases, teamwork and process support, administrator software. In order to follow the modification of these applications the number of versions and the updates must be documented properly. In case of unique software development, the project has to be documented from its initiation till its end. The completed software has to be audited as well. The developed software cannot be tested on the live system because it violates the aforementioned demands [8].

## SUMMARY AND CONCLUSIONS

Is it worth constructing and operating a server room? The question is at least as complex as the construction of it. Considering the aforementioned four factors the answer of a leader would be definitely no. But if we ask whether to entrust the precious business information to the care of somebody else only lead by our trust, and we even have to pay for it, then a responsible leader would most probably decide in the favour of the construction of an own datacentre. But as it has been introduced in the present essay the construction of a modern critical information infrastructure must be carried out on a very careful and well planned way.

According to the results of the network theory the construction and management of the infrastructure must be handled as a complex system. If this principle is not followed the weakest chain-link will ruin the effort in spite of the vast amount of money spent on the project. In the best cast scenario only its effectiveness will decrease but if it turns worse the interdependency will activate the domino theory, which will cause continuous malfunctions, decrease its effectiveness considerably [9, 10]. Consequently the maintenance of homogeneity is very important, but besides the developed infrastructure, the human resources, financing, training all have to be operated in a well-structured, centralized operational environment as well.

## **REMARKS**

<sup>1</sup>chain reaction like damage

<sup>2</sup>dependency on each other

<sup>3</sup>Control Objectives for Information and Related Technology

<sup>4</sup>Uninterruptible Power Supplies

<sup>5</sup>ElectroMagnetic Compatibility

<sup>6</sup>Very Early Smoke Detection Apparatus

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# ZAHTEVI NA POSTAVLJANJE I UPRAVLJANJE KRITIČNOM INFORMACIJSKOM INFRASTRUKTUROM

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## SAŽETAK

Dijelovi mreže mogu biti paralizirani serijom nasumičnih događaja ili dobro organiziranim ciljanim napadom. Ako znamo naš sustav i radimo uzimajući u obzir sigurnost, možemo izbjegći neugodne događaje poput pada sustava. Kritična informacijska infrastruktura postala je kompleksna mreža. Slijedom navedenoga, elementi sustava, njihove relacije i mapa mreže moraju biti poznati. Moramo prihvati kako je sve međusobno povezano tako kako fizičke i logističke mreže utječu jedne na druge. Očigledno je problem mapiranja kompleksnosti vrlo značajan. Pritom među najznačajnije dijelove ulaze prikupljanje i sortiranje informacija.

## KLJUČNE RIJEČI

mreža, struktura mreže, kritična infrastruktura, kritička struktura informacija

# TOWARDS AN AGENT BASED FRAMEWORK FOR MODELLING SMART SELF-SUSTAINABLE SYSTEMS

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## ABSTRACT

Self-sustainability is a property of a system; a system is considered to be self-sustainable if it can sustain itself without external support in an observed period of time. If this property is mapped to a human settlement in context of resources (water, energy, food, etc.), it would describe a human settlement which is independent of external resources (like the national electrical grid or a central water distribution system), where such external resources are either not available, or not desirable.

This article contributes to presenting the state-of-the-art overview of self-sustainability-related research. While self-sustainability as in the above described form was not a direct subject of research, there are several fields which are either related to, or could be of significant value to the self-sustainability research in this context. The extensive literature overview also showed no frameworks for modeling self-sustainable systems in the context of human settlements. Herein a motivation for using agent-based modeling and simulation techniques will be given.

## KEY WORDS

self-sustainability, sustainable development, multi-agent systems, agent-based modelling

## CLASSIFICATION

ACM: I.2.11, J.2

JEL: Q20, Q29

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## INTRODUCTION

Self-sustainability is a term which describes a property of a system. Any system that can sustain itself without the need of external support in an observed period of time can be labeled as self-sustainable. This kind of system could be used to describe self-sustainable human settlements, where this self-sustainability property could be measured. Such settlements might include remote/green villages/neighbourhoods/towns, but also underwater (deep sea) settlements, space settlements as well as manned space missions which need to be self-sustainable for the whole duration of flight.

While at the time of writing, there were no papers published dealing with self-sustainable systems in this specific context, fields of research that seem to be most related to certain aspects of self-sustainability, and which yield significant number of research papers, include sustainable development, intelligent building/houses, as well as, from a methodology standpoint, agent-based modeling and multi-agent systems. This paper will describe potentially useful concepts in the development of agent-based frameworks for modeling self-sustainable systems, like eco-feedback, load management, and some aspects of other research fields which are in a certain way related to multi-agent systems.

In the following a comprehensive literature overview of these connected fields will be presented and motivation for using agent-based modelling and simulation techniques will be provided.

## SUSTAINABLE DEVELOPMENT AND SELF-SUSTAINABILITY

The term sustainable development was first articulated by the United Nations in 1987 in the report of the World Commission on Environment and Development (WCED) as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1].

In 1994, John Elkington has proposed 3 aspects of sustainability: environmental, social and economic [2]. The main idea behind this ‘triple bottom line’ concept was that business activity can simultaneously deliver financial, social, and environmental benefits.

Many people have considered sustainability to be a synonym for energy-efficiency [3]. However, [4] argues that sustainability is not only about energy efficiency, but also about user’s comfort, well-being and cost savings. When building a self-sustainable community, user comfort is indeed one of the key factors in maintaining the self-sustainability property.

Because many alternative and modified definitions have emerged since (more than 140 [5]), the term “sustainable development” has acquired a broad meaning with no formal or generally agreed definition, and often implies long-termed, strategic development, or organizing principle.

When summarized together, main focus of nearly all sustainability goals seem to be a fair distribution of resources [6].

More concisely, dictionary definitions, define the word “sustainable” as:

- (a) “able to be used without being completely used up or destroyed”,
- (b) “involving methods that do not completely use up or destroy natural resources”,
- (c) “able to last or continue for a long time” [7],
- (d) “able to continue over a period of time”,
- (e) “causing little or no damage to the environment and therefore able to continue for a long time” [8].

The term “self-sustaining” is defined as:

1. "maintaining or able to maintain oneself or itself by independent effort 'a *self-sustaining* community'" [9],
2. "Able to sustain oneself or itself independently" [10].

By reviewing these dictionary definitions, the distinction between those two terms is fairly obvious; the most evident factor is "independence", present in the definition of "self-sustaining", while absent in the definition of the word "sustaining".

Self-sustainable communities imply a cyclical processes in terms of creating and using resources. Karl-Henrik Robèrt, founder of the Natural Step Initiative argues that "the only processes that we can rely on indefinitely are cyclical; all linear processes must eventually come to an end" [11]. He observes that our society is continuously processing natural resources in a linear direction, which in time reaches an end, thus being not sustainable.

There are several clear advantages in using self-sustainable systems opposed to using linear consumeristic models:

- a self-sustainable system is not dependent on availability, capacity or price fluctuations of the central resource distribution system,
- a self-sustainable system minimizes resource loss due to transportation, considering the small physical scale and compact nature of the self-sustainable system, in comparison with resource transportation lengths from central distribution systems,
- it assumes the usage of local renewable resources, which itself has numerous advantages over using fossil fuels for example, being the root problem for global warming [12],
- a self-sustainable system supports the ideas of resilient communities, transition movement, localization and permaculture [13],
- self-sustainability could help low-income families to achieve economic independence [14, 15].

As far as current linear model trends in energy supply and consumption go, numerous established organizations have stated that such trends are unsustainable [16, 17]. These organizations include International Energy Agency [18] and European Union [19-21] for example.

Related to these trends, the rise of greenhouse gas emissions (mainly CO<sub>2</sub>) is threatening the planet's global climate and chemistry [22].

However, during recent years, using renewable energy sources gained significant interest. The final purpose of exploitation of renewable energy sources is to move towards increased energy sustainability, and eventually complete independence from fossil fuel energy [23].

## **SELF-SUSTAINABLE SETTLEMENTS**

Self-sustainable neighborhoods/settlements are more feasible for implementing self-sustainable systems than it would be for individual houses alone. Resource production capacity for a house highly depends on numerous dynamic factors, for example the geographical position and orientation of individual houses, including a myriad of parameters of their local environment, and most importantly, on the complex behaviour of their residents.

For example, if a single person is living in a house, and he/she produces energy from "manually" burning biomass, the capacity of the house for this resource production is limited to times when the person is at home. However, in order to retain some defined comfort level, those resources might be needed before the person arrives. These resources could be transported from another unit/house per request. From such viewpoint, a network of resource production/consumption units could be realistically more feasible for implementing a self-sustainable system, than it would be for a single house. [24] notes that self-sufficiency can "hardly be achieved in a single household."

Sustainable neighborhoods would achieve three broad sustainability goals: eco-efficiency, eco-equity and eco-effectiveness [25].

Interestingly, already in about 400 BCE, Aristotle referred several times to a self-sufficiency concept in his work titled *Politics*: “*For a household is more self-sufficient than an individual person is; and a community of a mass of people counts as a city only if it proves to be self-sufficient*”. “*A city is the community of families and villages in a complete and self-sufficient life. This sort of life, as we say; is a happy and fine life; hence we should suppose that a city aims at fine actions, not ‘merely’ at living together*” [26].

## AGENTS AND INTELLIGENT BUILDINGS

“An agent is a computer system that is situated in some environment, and is capable of independent (autonomous) action in this environment on behalf of its user or owner, in order to meet its delegated objectives.” [27, 28].

An agent is independent in a sense that it can figure out for itself what it needs to do in order to satisfy its design goals, rather than being explicitly instructed about what action to follow in every possible case scenario.

A multi-agent system is one that consists of a number of agents which interact with one another; such a system can be observed as a system with multiple interacting components. In order to successfully interact, these components (agents) must cooperate, coordinate, and sometimes even compete, negotiate and argue with each other.

An essential ability of an agent must be its ability to learn from experience and hence adapt appropriately [29]. The authors of [29] further argue that this notion implies a system which can adapt and generate its own rules, instead of being restricted to simple automation. They define an intelligent building as one that uses computer technology to autonomously operate the building environment for optimization of energy consumption, user comfort, safety and monitoring functions.

Intelligent building/houses/homes involve certain computerized scheme (for example, multi-agent systems) which regulates building components, utilities, electrical circuits, and heating, ventilating and air-conditioning systems in order to monitor building functions, security, energy consumption, and provide a comfortable environment to users [30]. Furthermore, [31] argues that intelligent buildings should not only be modeled as multi-agent systems (MAS), but should include learning capabilities to adapt to the user’s need and changing preferences.

The [32] proposes the development of a new subfield of IS called energy informatics, which recognizes the role that information technologies could play in reducing energy consumption (resulting as well in reducing CO<sub>2</sub> emissions) and they present their core idea with the following illustrative expression:

$$\text{Energy} + \text{Information} < \text{Energy}.$$

As noted in [33], the environment of intelligent buildings is very complex: inaccessible, non-deterministic, non-episodic, dynamic and continuous, and it is suggested that a feasible solution for controlling it would be to implement adequate multi-agent systems [34]. Further, it is suggested that if a problem domain is “particularly large, complex, or unpredictable, then the only way it can reasonably be addressed is to develop a number of functionally specific and (nearly) modular components (agents) that are specialized at solving a particular problem aspect” [35].

Relating to above mentioned modular components, it would prove beneficial for a modeled self-sustainable system to have the possibility to be open-ended and extensible, as there might be a need for adding new resource sources, or removing existing loads at any time, without having an impact on the overall operation of the system.

In [29], authors have defined a set of behaviours for an agent responsible for autonomously governing the building environment:

- safety behaviour (for example, light levels are always at safe levels),
- efficiency behaviour (for example, it should turn off the lights when there is no presence in the room, or if there is sufficient natural light present),
- emergency behaviour (controls resources in an emergency situations),
- manual behaviour (complete control of the user, and it reacts to any orders the occupant gives it),
- self-taught behaviour (adapts to different users and environments).

The agents in the mentioned paper do not contain complex modelling or reasoning capabilities, because these might be very processor-intensive. Whilst limited, this approach ensures that the system is able to respond in real time on any situation or event.

Similarly, [36] decomposes agent behaviours into 4 behaviour subsets, and defines hierarchy amongst them: Safety behaviour has the top priority, following by Emergency, Efficiency, and Comfort behaviours. However, their architecture is not limited to these pre-defined behaviours, but it also “has the ability to learn new behaviours dynamically, based on actions taken by occupants within the room.” Learning mechanism is derived from the CASE based learning, a branch of traditional AI work [37].

MavHome (Managing an Intelligent Versatile Home) is a project supported by National Science Foundation which is focused on creating a home that acts as an intelligent agent [38]. Authors introduce the MavHome architecture, discuss the role of prediction algorithms, and present a meta-predictor “which combines the strengths of multiple approaches to inhabitant action prediction.” Authors define the need for a number of capabilities for their smart home scenario and its integration: machine learning, mobile computing, robotics, databases and multimedia computing.

Article [24] raises the question “Can we make smart home sustainable or sustainable homes smart?”, and discusses current trends and challenges arising with these questions. Along with illustrative examples of some real-life efforts of designing sustainable homes, authors elaborate critiques and problems regarding smart homes, like increased energy consumption, electronic waste [39], user frustration and cognitive overload [40], and similar, which need to be addressed in order to make smart home sustainable.

Authors of [34] found 72 literature sources identified to have potential significance on some aspect of agent technology in intelligent buildings domain.

## **ECO-FEEDBACK**

Indeed, it has been researched that supplying consumers with information about their energy usage can lead to changes in usage patterns, and decrease in overall consumption [41, 42].

The [43] claims that the use of real-time feedback can decrease energy consumption by 10 % - 20 %.

The [44] found 133 papers (89 papers from environmental psychology and 44 papers from the human computer interaction and ubiquitous computing literature) that report about eco-feedback. It shows that the monitoring of energy consumption has the potential to make users aware of

the hidden details of their current behaviour, as well as about how he compares to other community members.

When receiving this eco-feedback, users can clearly see their consumption footprint, and they become more able to control their energy usage. At the same time, eco-feedback is informing them about usage of other users, which provides increased social awareness in the household [45-47].

The [47] presents a study where a minimal in-home energy consumption display encourages users to identify high-power devices in their home, and to reduce energy consumption.

Article [48] designed, implemented and evaluated an interactive visualization that allowed users to engage with and understand their consumption data. Validation of this design included 12 participants who installed meters in their homes and used the system for a period of two weeks. Results were that the users started to relate energy consumption to activities, rather than just appliances, and were able to discover that some appliances consume more than they expected. The results also indicates that there is a “potential for interactive eco-feedback technology that engages users with their data beyond mere presentation”.

## LOAD MANAGEMENT

Load management mechanisms are presented in [49], according to distribution control described in [50]. These mechanisms allow time adjustments of certain services/appliances in order for them to operate in time periods when global resource consumption is lower, and/or resource price is lower. To achieve this, a load management system designer must observe that some services/appliances can be delayed, some can be reduced, some services programmed to run according to the weather forecast, energy could in some cases be accumulated for later use, etc.

Demand side management is a method designed to coordinate the activities of energy consumers and energy providers. This method seeks to avoid so called peaks of energy consumption [50].

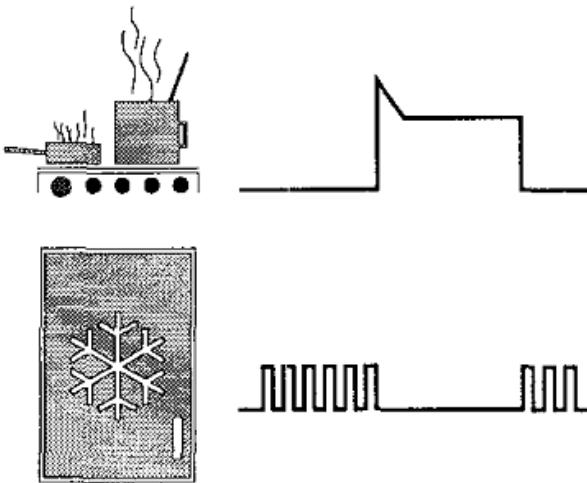
This method could be significantly valuable to the modeling of self-sustainable systems, because it could prevent consumption peak times which have the capacity to deny the system of the self-sustainability property (extremely high resource demand in the short time interval). The main idea is to smooth the energy consumption by using intelligent domestic appliances that communicate and coordinate with each other.

As an illustrative example, there could be software agents embedded in the appliances, which can negotiate about which of them needs to be temporarily interrupted in the case of unscheduled events like resource shortage, or unforeseen resource consumption (this is called “intelligent load shedding”). Each of the agents can permanently monitor satisfaction levels of its services, and take appropriate actions according those levels.

The article [50] presents a system for power consumption distribution in private homes uniformly over time, where logical relation between devices is established, and energy consumption policy is coordinated between them. All this is taking place in a distributed, autonomous infrastructure. Figure 1 illustrates the short-term power management of appliances, where energy consumption peak is avoided [50].

Shift of energy usage load for avoiding peak times for reducing the need for high production capacities has been identified as one of the keys for energy efficiency [51].

Similarly, objective of the study in [49] was to “design a building electric energy management system able to determine the best energy assignment plan, according to given criteria”.



**Figure 1.** Short-term power management of appliances for avoiding peak consumption – illustrative example [50].

Based on a large literature overview and documented cases, [52] concludes that the “main operational benefits of installing intelligent building components include:

- (i) energy efficiency and higher environmental sustainability;
- (ii) increased user comfort and productivity;
- (iii) improved safety and reliability;
- (iv) improved operational effectiveness; and
- (v) enhanced cost effectiveness.”

Authors also suggest that the input that environment gives to agents cannot be specified in advance. They gave an illustrative example: “something happens to one system (e.g. reducing light level) may cause a person to change behaviour (e.g. sit down) which in turn may result in them effecting another systems (e.g. needing more heat); and people are essentially non-deterministic.” Since there is a myriad of home appliances which consume resources, they have proposed grouping all these operations of different appliances into the term “service”. This “service” transforms energy in order to meet a user’s need via one or several appliances, and could be qualified as permanent, or temporary, depending on its usage of energy.

Second important notion from the same paper is the “satisfaction function”, which defines “user comfort” in terms of delivered service regarding the user’s feelings, which is close to the notion of personal satisfaction from [53].

## OTHER RELATED FIELDS

The field of distributed/concurrent systems has been investigating properties of systems with multiple interacting components, and there are theories, programming languages and tools developed in order to explain, model and develop such systems [54-56].

In order to distinguish concurrent systems from agents, we can argue that agents are assumed to be autonomous, and their mechanisms allow them to coordinate their activities at run time, instead of being hard-wired at design time. Moreover, agents are presumed to be self-interested entities, whereas in a classical distributed/concurrent system, all the components of a system share the common goal.

Game theory is a mathematical theory that studies interactions among self-interested agents [57], which plays a major part in use for the analysis of multi-agent systems as the predominant theoretical tool. However, many of the solution concepts developed in game

theory “were developed as descriptive concepts, without a view to computation” [27]. Multi-agent systems research allow the use of tools of computer science such as computational complexity theory [58, 59].

Artificial intelligence is mainly concerned with the components of intelligence, and agents are entities that integrate these components. For this reason, AI could be perceived as part of the construction of agents [27].

Expert systems deal with detailed knowledge in a defined domain, and are able to solve problems or give advices in the context of that domain [60]. Although some expert systems might resemble agents, there are several key distinctions: expert systems are usually not connected directly to any environment; they are generally not equipped with social abilities; nor they are generally capable of proactive behaviour.

The Internet of Thing (IoT) is a novel field defined as “a variety of things or objects (...) which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbours to reach common goals” [61]. These things include numerous different devices including but not limited to sensors and actuators of various kinds, mobile devices, TV sets, car/vehicle computers; but also non-ICT appliances (dishwashers, microwave ovens, refrigerators), electrical energy sources and building components [62].

Some of the key application areas of IoT are smart cities [63], smart power grids [64], smart health [65], smart transport [66], as well as smart buildings [67] which includes smart living solutions [68].

Most of these publications can and should be considered when dealing with smart self-sustainable communities, since they deal with detailed theoretical and practical models of implementing smart solutions for residential facilities.

## **TOWARDS AN AGENT-BASED FRAMEWORK**

From the previous contemplation it becomes obvious that smart self-sustainable settlements are complex, socio-technical systems which are hard to plan, model, implement and sustain. There are currently no adequate solutions for modeling and simulation of such systems which is why herein we propose to take an agent-based approach.

Agent-based modeling is a natural methodology to analyze and build such systems, given the large number of non-deterministically interacting components (agents) including but not limited to humans, various sensor and actuator equipment as well as environmental influences. The various possible interaction models like automated negotiation protocols, argumentation, resource allocation (possibly implemented using auction protocols) as well as different machine learning and artificial intelligence techniques for interaction with the environment and human behavior, induce this complexity to an even higher level. Such systems of greater magnitude cannot be simulated efficiently using traditional simulation techniques.

The potential benefits of using an agent-based modeling approach are threefold:

1. it allows us to determine if and for how long a settlement will be self-sustainable through simulation,
2. it allows us to experiment with different configurations of various equipment and environmental influences before actually building a settlement,
3. it allows us to analyze existing settlements and provide solutions to enable/enhance self-sustainability.

In order to use agent-based modeling a framework that establishes a common ontology of the field has to be established. This ontology has to include available knowledge from all the above mentioned fields of research but also go further and formalize important terms and metrics dealing with self-sustainability.

## CONCLUSION

In this paper an overview of available literature in the field of self-sustainability, and related fields was given. Most important concepts such as sustainable development, intelligent buildings, eco-feedback, load management, user satisfaction function, etc. were identified. While there were no significant research papers found on the subject of self-sustainability of human settlements, there is a large number of papers published in the related fields of sustainable development and intelligent buildings, which describe certain aspects and tools that have the capacity to be used in the research of self-sustainable human settlements.

A clear distinction has been made between two at-first similar concepts "self-sustainability" and "sustainable (development)". Self-sustainability refers to the property of a system, whilst sustainable development encompasses a broader meaning, a strategic development, or organizing principle, which strives to "smarter" use of natural resources.

Self-sustainable settlements can be viewed and modeled as self-sustainable systems, where all the needed resources for the settlement are produced locally, without the need to transfer the resources from external sources. The main challenge of such settlement is the answer to the question: when taking into account all the relevant parameters (resource production capacities, residents, etc.), can this settlement be self-sustainable for some defined time period?

The authors suggests to design a framework which uses agents for modeling such self-sustainable systems, and which will enable a direct answer to this question. The framework should be able to determine if the transit to a resource-independent community, which would use local, renewable energy sources, is possible (for a specific case-study), but should also be able to design such a resource-independent community, providing all the parameters needed to achieve the self-sustainability property.

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# **RAZVOJ AGENTNOG OKVIRA ZA MODELIRANJE PAMETNIH SAMO-ODRŽIVIH SUSTAVA**

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## **SAŽETAK**

Samo-održivost je svojstvo sustava; sustav smatramo samo-održivim ako je u stanju sam sebe održati bez pomoći iz okoline u promatranom vremenskom razdoblju. Ako ovo svojstvo primijenimo na ljudska naselja u kontekstu resursa (vode, energije, hrane itd.), ono opisuje ljudsko naselje koje je neovisno o vanjskim izvorima (poput nacionalne elektroenergetske mreže ili centralnog vodovoda), pri čemu takvi vanjski resursi nisu dostupni ili nisu poželjni. U članku daje se pregled najrecentnijih istraživanja vezanih uz samo-održivost. I dok tako definirana samo-održivost nije bila izravno predmet istraživanja, postoji nekoliko područja koja su vezana uz samo-održivost ili su od signifikantne važnosti za istraživanja u ovom kontekstu. Obuhvatni pregled literature također je pokazao da ne postoji okvir za modeliranje samo-održivih sustava posebice u kontekstu ljudskih naselja. U skladu s time, daje se motivacija za korištenje agentnih metoda za modeliranje i simulaciju u ovom području.

## **KLJUČNE RIJEČI**

samo-održivost, održivi razvoj, višeagentni sustavi, agentno modeliranje



# MODULAR APPROACH TO DESIGNING COMPUTER CULTURAL SYSTEMS: CULTURE AS A THERMODYNAMIC MACHINE

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## ABSTRACT

Culture is a complex non-linear system. In order to design computer simulations of cultural systems, it is necessary to break the system down into sub-systems. Human culture is modular. It consists of sets of people that belong to economic units. Access to, and control over matter, energy and information is postulated as the key to development of cultural simulations. Because resources in the real world are patchy, access to and control over resources is expressed in two related arenas: economics (direct control) and politics (non-direct control). The best way to create models for cultural ecology/economics lies in an energy-information-economic paradigm based on general systems theory and an understanding of the “thermodynamics” of ecology, or culture as a thermodynamic machine.

## KEY WORDS

cultural ecology, thermodynamics, systems theory

## CLASSIFICATION

JEL: N51, N91, O13, Q22, Q57  
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## INTRODUCTION

The separation of environment from culture is artificial. It is my view that the environment consists of three interdependent sub-sets:

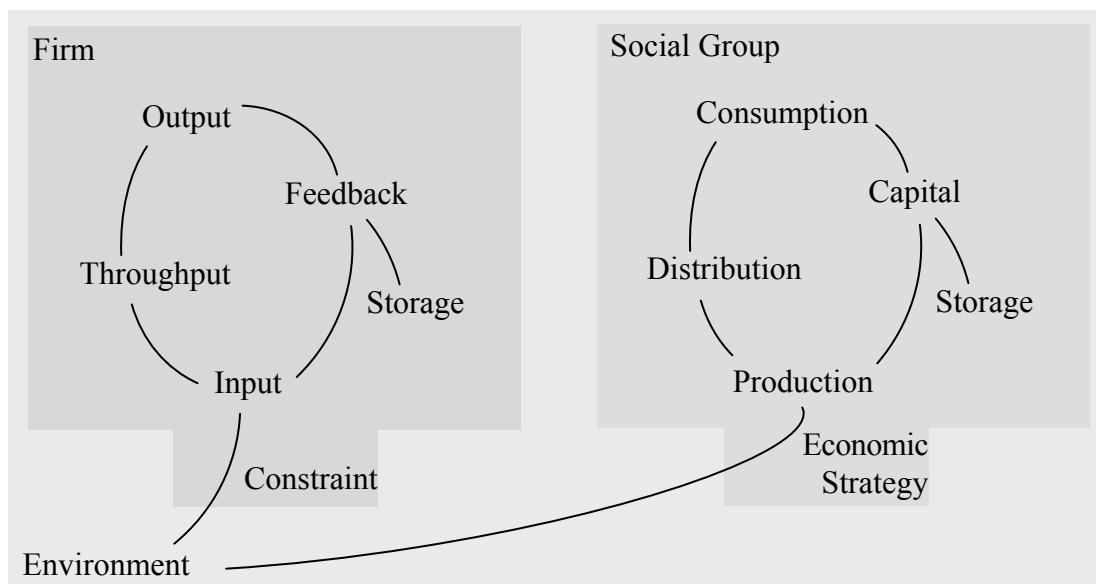
- 1) The physical environment consisting of geomorphic surfaces and their hydrologic structure within a climatic regime (soils, topography, light, humidity, temperature, seasonality, rivers, streams, lakes, ponds, oceans, etc.). It includes a mosaic of minerals valued by human groups. The physical environment tends to be the slowest to change, fluctuate and also tends to be the most predictable for modeling. Key variables in this sub-system include water, minerals such as tool stone, relative climate impacts to plant and animal distributions and seasonality, presence or absence of water in hydrological systems and ambient temperature relating to factors such as shelter. At a gross level, variables tend to be more simplistic and mechanical as well as linear. This environment tends to be dominated by “matter” as a resource, but must be “mapped” and “categorized” as information,
- 2) The biotic environment consisting of plants and animals and their ecological relationships to the physical and cultural environments (distribution, biomass, diversity population, etc.). This sub-system is more likely to change, fluctuate, and is more difficult to predict and model. Key variables include plants for food, fiber, and wood for tools and cooking; animals for food, hide, fur, feathers, bone and sinew. Variables tend to be more complex and non-linear. This environment tends to be dominated by “energy” as a resource, but is based on matter and must be mapped and categorized by informational systems,
- 3) The cultural environment consisting of cooperating and non-cooperating other human beings and their relationship to the physical and ecological environments. This sub-system is the most likely to change, fluctuate and is the least predictable for modeling. The key variable is the cultural idiom for access to, and control over resources, and information about the location, distribution and relative abundance, activity and predictability of resources in all three environments. Culture is the idiom that expresses, in symbolic forms, how human groups map access to, and control over, valued resources. This environment tends to be dominated by “information” Culture is an informational milieu.

A thermodynamic characteristic (in fact, requirement) of cultures is their ability to map out matter, energy and information about resources, their relative distribution, relative abundance, relative activity, and relative predictability. There is an isomorphic correlation between the form (demands) of general living systems and economics as a model. This is why economic models work so well. Since economics and ecology share common roots, ecological models also work well in anthropology.

“The environment, however else it may be characterized, can be seen at bottom as a set or ensemble of more or less distinguishable elements, states, or events, whether the discriminations are made in terms of spatial or temporal relations, or properties. Such distinguishable differences in an ensemble may be most generally referred to as ‘variety’. The relatively stable ‘causal’, spatial and/or temporal relations between these distinguishable elements or events may be generally referred to as ‘constraint’.... When the internal organization of an adaptive system acquires features that permit it to discriminate, act upon, and respond to aspects of the environmental variety and its constraints, we might generally say that the system has ‘mapped’ parts of the environmental variety and constraints into its organization as structure and/or ‘information’” [1; p.491].

Humans are born into family groups. Such groups must have access to, and control over, resources necessary and sufficient for self-maintenance and growth. Growth is a requirement simply because all life must push against its inherent limits and random chance disorder. If life did not do this, it would cease to exist sooner or later. Human groups, usually based on kinship in small-scale societies, form the basic economic firms of production, distribution, storage and consumption. These are the modular units that are basic to this paper. They are essentially identical in small-scale societies, and grow in variety and complexity with population growth and in the face of increasing demands and supports. They can be modified through their respective economic technologies of production, distribution, storage and consumption. They can be modified through their technologies of political control as well. In addition, within each of the three sub-environments are variables that can be manipulated to modify carrying capacity. As might be expected, the more active and symbolic variables are subject to the greatest chance for manipulation and change ... in fact, they are designed for manipulation. The symbolic idiom is set up to be loose, and allow for changing circumstance as the players change as they are born, age and die.

Figure 1 illustrates the model of the interrelationship between the demands of systems frameworks and economic terms. The general systems terms are on the left and their isomorphic economic parallels are on the right.



**Figure 1.** Model of the interrelationship between the demands of systems frameworks and economic terms.

All systems consist of sub-systems that are isolated from other sub-systems as “entities” by a set of constraints (i.e. they have limited material, energy and information flows at some boundary) as well as a primary means of material, energy and information input (constraint). The sub-system is an “entity” of “firm”, an internally related group of variables more or less isolated (never completely) from external factors. The correlation between systems variables and economic variables is clear from Figure 1: input equals production, throughput equals distribution, feedback equals capital or investment, output equals consumption, while storage is “feedback” kept on hand more or less in stasis until needed. The basic constraint is a set of variables that control input which is the economic and political strategy (adaptive framework) of the social group or “entity”. Just as feedback (material, energy or information) is used to modify input, throughput or output ... capital/investment (material, energy or information) is used to modify production, distribution and consumption.

In small scale societies where storage capability is limited, energy is stored less often as food material and more often as information through “reciprocity” (i.e. invest or convert short shelf-life goods to immediate use by cooperating other human beings, and create a “debt” that can be called in the future stored as information ... which has a longer shelf-life).

Social groups or entities, use exploitative technology and strategies to maintain access to and control over valued environmental resources: physical, biotic and cultural. They gather resources directly or store information about resources and their relative abundance, predictability and activity. They also create a complex cultural idiom to store or invest matter, energy or information for manipulation of cooperating and non-cooperating other human beings. If kinship, marriage, economics, politics, law, warfare and religion are examined within this paradigm, they show up as complex “maps” of control systems. They are a form of ecological contracts between parties expressed in complex symbolism. Since circumstances change, since living systems are dynamic, and since individuals are born, grow through stages, and die, the contractual idiom is kept in symbols that can be interpreted in many ways (deliberate vagueness). In small scale societies, their re-interpretation is the subject of almost constant public consensus debate. In large scale societies, re-interpretation keeps lawyers employed.

Breaking down societies into modular “firms” is my way of modeling the cultural ecology of human groups. It creates a simplified but valuable tool to understand how a particular society functions.

Language is a technology, no different than technologies of production, distribution and consumption. Language and symbols are a symbolic milieu constructed with the intent of “looseness” (randomness) or noise. The idiom is designed so that it can be interpreted and reinterpreted by constant “consensus” activities (that oscillate and converge on some broad and loose meeting for many players and agendas). Language is designed to allow communication of symbols but at the same time to be non-linear in interpretation. It is not designed to be precise, but to be vague as to allow for changing circumstances. It must be rich and complex and non-linear as it reflects the complex inter-relationship between the physical, biotic and cultural environmental sub-systems. Language is simply a technology, a way on manipulating not only the hard physical resources of the three sub-systems, but as a way of manipulating cooperating and non-cooperating other human beings in relation to those resources (including the humans as resources and their “information” about the resources) and access to, and control over, those resources.

“Cybernetics is the science of communication and control. As such, it does not examine transformations of energy. It examines patterns of signals by means of which information is transmitted within a system and from one system to another. Transmission of information is essential in control, and the capacity of a system to exercise control depends on how much information it can process and store. In fact, the concept ‘quantity of information’ is central in cybernetics. In this context, ‘quantity of information: is unrelated to the meaning of the information, its significance, or its truth. Quantity of information is related simply to the number of decisions’ which must be made in order to reduce its range of possible answers to the question one asks; to put it in another way, to reduce uncertainty” [1; p.xix].

The term “production” is a linguistic tag for “input”; “distribution” is a tag for “throughput”; and “consumption” is a tag for “output”. There has been recent work in “fuzzy” theory concerning the meaning of words as mathematical sets. Fuzzy logic expresses the world in both terms of possibility and probability. It uses logic truth-values associated with words, not numbers. Fuzzy truth tables are imprecise and fuzzy rules are approximations. Bart Kosko was able to prove through hypercube matrix analysis that probability, including Bayesian

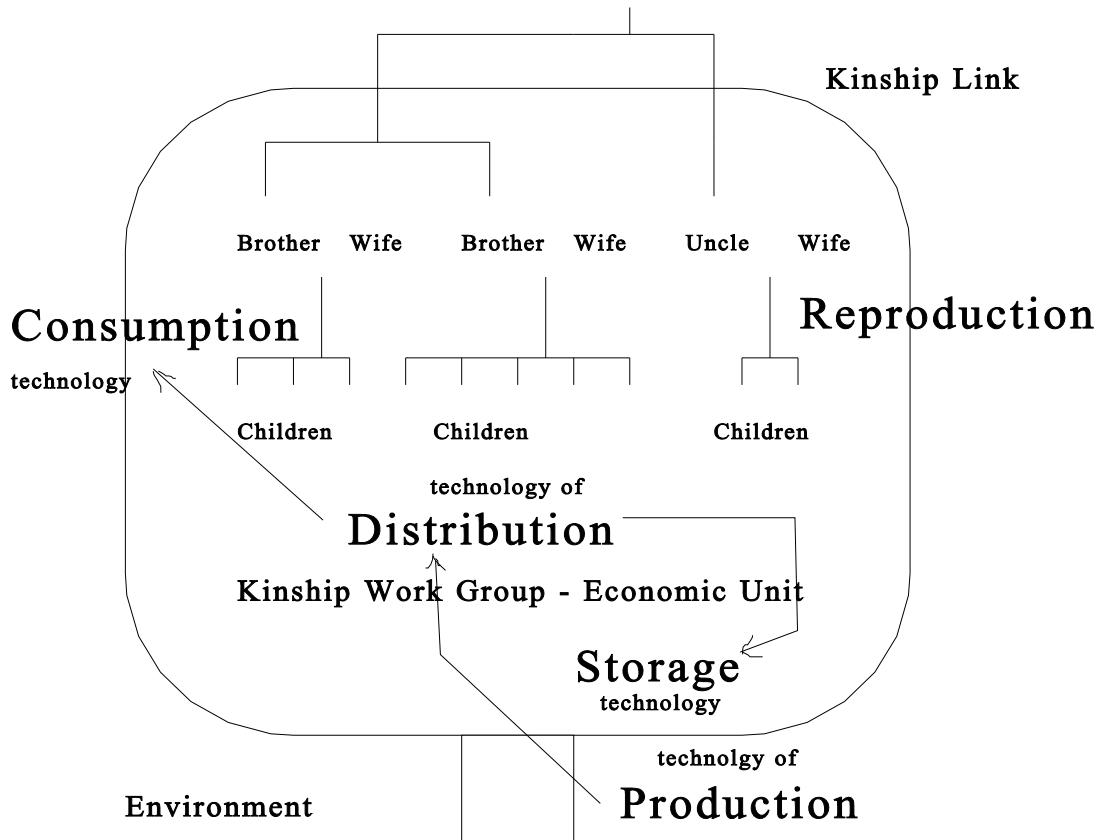
axioms, is a subset of fuzzy theory. In showing that axioms of probability can be derived as a theorem that can be proved under fuzzy logic, he relegated probability to a sub-set of fuzzy logic [2-4]. Fuzzy logic may be the key to breaking the thermodynamic code of language.

As noted. Growth is a requirement of life. Humans are living creatures. As human populations expand, the demands on resources increase and the pool of players increases. As such, it has what appears to be evolutionary change, if one views increasingly populous systems as falling into some kind of evolutionary ladder. They do become more complex, simply because of the law of large numbers: any complex system branches into sub-systems. This is a practical reality ... sub-systems specialize to allow increased complexity. A complex multi-cellular living being cannot live without sub-systems such as digestion, information response, processing, circulation, etc. This is exactly what happens in cultural systems as well. With increasing population loads, the culture breaks up into specialized sub-systems (or firms). In evolutionary terms the amount and variety of such specialized sub-firms can be used as a measure. With such proliferation, there is the growth of specialized symbols that define the operation or process of the sub-entity. As complexity grows, there is asymmetry and every asymmetrical, connected, and transitive relation establishes a serial order. The cause produces the effect and the effect records the cause. Anything is possible, but fewer things are probable.

All information is a form of “capital” as well as a “resource”. In highly complex systems, the young must be taught the necessary and sufficient information for basic survival. Some will recognize that mastery of this “information” is the key to relative wealth. This allows some level of asymmetrical use of information in all systems. The smaller the system the more homogeneous it is in structure and there are fewer opportunities for relative wealth. But at all levels there is some leeway. There are always some who score a bit more of the resource pie, who are a bit more able in symbolic manipulation, who “play the game” with a bit more élan or skill. Small-scale societies are tied more directly to their biotic and physical environments than complex ones. The agent(s) of production, distribution and consumption tend to be limited to a person, family or other kin groups. Social groups tend to be homogenous, each pretty much a mirror image of all others. The more complex and larger the society, the more diverse social entities can become and the more divergent in structure and composition they become. They can also become specialized sub-entities, with little to do with primary food, material or energy production. This modular nature of cultural systems is the key to computer simulation models.

The proliferation of specialization, in productive firms in more complex societies, means the proliferation of specialized jargon. As any technology is changed through some artifact invention or some way of “defining” access to, or control over any physical, biotic or cultural resource ... terminology expands. This applies not only to the internal economic realm, but also to the patchy political realm of control. Just as an economic firm may specialize in distribution of a resource, or the production of a resource, in complex systems, those who pull the political strings can specialize into the political arena of social control over patchy resources. As information proliferates and specializes, groups can capitalize on control over information as a resource. All resources contain some level of information about their location, their motility, their relative abundance, etc. In addition, technologies related to their exploitation (production, distribution, consumption, storage) are subject to access and control issues (politics).

In low-level population density ecological systems, free access to essentially all facets of production, distribution, consumption and storage is validated in the shared linguistic system. As populations grow, and specialization occurs in productive and/or political firms ... specialized terminology grows. As such, this form of information becomes a kind of capital as well.



**Figure 2.** Example of an uncomplicated family-based cultural system unit.

There arises the possibility, indeed the probability, of firms devoted to controlling information alone as a product. Not only do complex systems become asymmetric in relation to production, but complex societies thus become asymmetric in relation to the society's own language!

### ONLY VARIETY CAN REGULATE VARIETY!

Figure 2 is an example of an uncomplicated family-based cultural system unit. The example is based on a patrilineage model. Groups of related brothers, their wives, and children, perhaps uncles and their families, become the basic economic unit of production, distribution, storage, and consumption. They exploit the environmental resources as a cooperative unit. They may own rights to specific resource plots together. They may include other relatives who prefer their company and benefits. Such a unit may be the basis for a complex winter pit-house, where each family has a hearth and associated bed-shelf around a common hearth area. The eldest brother may be the group leader for political activities in relationship to patchy resources and non-cooperating other human beings. Such a unit would repeat over and over in small-scale societies, only the numbers of participants and their skills making the little difference between any two units of economic or political power. Cultures can be broken down into such production units. The larger, and more complex the system, the greater variety in unit function. Units in very complex systems can be so specialized that they take over a single aspect such as relatively pure production, or distribution. Units may specialize in type of production, or gain specific technical skills to produce artifacts or information for distribution in exchange for matter, energy or information. The repeatability of such units allows modeling of cultural systems.

Cultures change because of changes in the physical, biotic or cultural environments and more importantly because populations grow. Any variable in the complex system can change and thus change carrying capacity. Technologies of production, distribution, storage, and consumption will change as each unit of production jockeys to meet its internal demands. Production units can attempt to increase access to, and control over, valued resources in all three environments. The adaptive/economic strategy can be modified, and this modification will modify carrying capacity. The resultant changes are often seen in “evolutionary” terms in anthropology. There is nothing linear about which variable or combination of variables might change. Change in any variable tends to create the possibility of more change in that variable (within self referencing limits) because of feedback loops. There can be gradual changes in existing variables or a change in degree so great as to be a change in “kind” of the variable. For example, gathering can intensify within a natural biotic system. Groups can shift to fire to modify a biotic system (low level plant/animal management) to increase valued biota, but still gather wild plant products as the primary source of production. Groups can then begin to manipulate the plants and/or animals such that they are no longer natural species, and are now dependent on humans. Groups are no longer gatherers, they are plant/animal managers (i.e. agriculturalists/herders).

Politics is generic managerial control over, and access to, valued resources of the society of cooperating human beings as a whole as opposed to non-cooperating other human beings. No social group operates in a vacuum. All resources are irregular in distribution and density. All groups impinge on the resource territories of other groups. This interleaving of resources and resource needs creates a demand for access and control systems expressed either as economics (mostly internal) or politics (mostly external). They blur together at many levels within the idiom (symbolism) of the culture. Politics evens out patchy resource issues.

All human beings operate within a social framework defined in the cultural idiom. All human beings exploit matter, energy and information in a social matrix of cooperating and non-cooperating other human beings. Cooperative economic and political action reduces variation in access and control over valued resources and changing conditions. Cooperative sharing of information within a cultural framework increases the range of information about the three environments, increases alternatives for dealing with fluctuations in the distribution of valued resources. It also increases alternatives in the face of random chance disorder as well as increases access and control in the face of non-cooperating other human beings. There is always some point where human beings are in a position of competition, active or passive, for valued resources. This can arise from internal or external expansion in numbers. Cooperative economic and political action reinforces mutual rights and smooth out differential distribution of resources within the environments. For example, in many slash and burn agriculturalists, active and fallow fields co-mingle. Group control over fields allows many sub-groups based on expanded family kinship groups access to fallow fields as resources without active competition. Group cooperation creates a mosaic of zones and relationships that express this active and passive cooperation and passive and active competition. Human beings manipulate each other through symbols (the cultural idiom) to control access to such resources.

The network of interrelated and intercommunicating human beings creates social groupings. Shared needs and values decrease to competitive needs and values through a continuum. The fundamental social “entity or firm” is found repeating throughout the social system within variations. Each person is born into an existing cultural milieu. Each person learns the network of demands and supports from nearby other human beings. Not all learn the same information, and the information is always “loose” to allow manipulation. This shared learned information is the cultural idiom. Some members are better at the process than others. The symbolic idiom sometimes seems superficially remote from human-land, human-biota, and human-human relations. The very active human side of the equation often masks the

more passive biotic and land relationships. Symbols can represent an action, or class of actions, with its/their associated demands and supports.

Other human beings, whether cooperative, or non-cooperative, are the patent manipulators and are the most active variables in changing relationships to resources. People manipulate people to reach a real energy, matter or informational end. Manipulation of people through complex symbols is the means to an end. There is never one solution, but a complex and very rich cultural idiom that defines access to, and control over, valued resources in all three environments.

Culture is thus a dependent phenomenon of this manipulation and is isomorphic to the demands of living systems and the thermodynamic process. It operates as a filter between human beings and human groups. It contains latent values (associated with matter, energy and information) related to access and control of resources and all resources are patchy to some extent. There are seasonal and long-term cyclical and linear patterns of changes in the physical environment. The biotic sub-system fluctuates more strongly seasonally and also exhibits climax vegetation and long-term cyclical and linear changes as well. The cultural sub-system is the most active in change and fluctuations (fission-fusion-flux).

Because all resources are patchy to some extent, political idioms are created. There are seasonal and long-term cyclical and linear patterns of changes in the physical environment. The biotic sub-system fluctuates more strongly seasonally and also exhibit climax trends and long term cyclical and linear changes as well. The cultural sub-system is the most active in change and fluctuations (fission-fusion-flux). All resources can be placed into a scale that defines them as relatively predictable, relatively abundant and relatively active or sessile. Physical resources are the most predictable and the most sessile, and abundance is patchy but fairly universal regionally. For those resources that are valued and very patchy, trade networks arise for their distribution. Biotic resources of importance to the primary exploitation strategies tend to be those that are the most abundant, predictable and sessile within the demands for food, fiber, wood, skins, sinew, bone and horn (there are others like feathers, fur, claws, etc) as well as such things as “taste”, “texture”, “odor”, as factors in value and use.

“A system cannot be regarded as stable unless there is a guarantee that the resources on which it depends will always be available. The only way it can ensure this is to live off the interest and not the capitol of available resources” [8; p.73].

A system containing non-biological (cultural) technologies can change the technology as a form of interest on resources, increasing output (production), increasing efficiency in any sub-part, etc.

Although the model is matter/energy/information dependent, there is no one to one correlation between social entities and their complex of environments. All social entities have an exploitative strategy that is a mix of all three environments. Every strategy is a compromise reflecting all three as subsystems of an overall environmental exploitation process.

Another key aspect to this cultural overview is culture’s symbolic milieu (religion). As cultural animals, humans create rich symbolic idioms that attempt to categorize and understand everything.

Human culture is a symbolic milieu for operation of a thermodynamic machine filled with non-linear mutual causal feedback loops. It is designed to be loose, to be subject to differential consensus or interpretation. But it is also inherently systemic and thermodynamic in its internal firm-like structures are used to control interaction with the physical, biotic and cultural sub-systems. It is modular. Religion is the “symbolizing” of the symbols and related

processes. It validates access to, and control over, valued resources in the physical, biotic and cultural environments.

Anthropology has shown, for example, that burial of the dead is often used to validate ownership rights over resources. Burial mounds in the Midwest, are political and economic statements. A mound starts with a burial. As more burials are added, the mound gets larger. The mound, and its contents, is a visual signal. Burial in the mound is proprietary, so the presence of ancestor burials validates claims of historical continuity. The bigger mounds demonstrate longer and greater claims. Political units are defined by hierarchies of burial mound size.

In the Mayan area, temple mounds served similar purposes. Temples were built over at regular calendar intervals. The large late temples contain older temples. Each temple was a place for blood offering for a political group based on kinship. The relative temple size was a measure of political longevity in dynastic power. The large stone burial tombs in ancient Britain had the same purpose, visible statements of kin group history and control of a region: we are what our ancestors were, we are where our ancestors were buried ... your ancestors are not buried here ... you have no valid claim. The size of the burial complex relates to the size and longevity of the claim.

How important is material culture technology and/or style in these issues? Technology is just one aspect of human adaptation. There are technologies of production, technologies of distribution, technologies of consumption and technologies of storage.

Since human beings exploit all three environments, it is possible to expand storage “technology” through reciprocity by giving excess perishables to kin groups with the expectation that when similar excess occurs within their group in the future, you will get similar perishables back in return. This is a form of “technological” storage of information about an exchange and the debts incurred through such an exchange. Such technological forms may not appear in the archaeological record, but are real, and very common. Mentally mapping the environment, knowing its seasons and patterns, knowing where things are, and how to access them are all technologies. Sharing such information and expressing this information in complex cultural idioms is a form of technology.

I believe that the best way to create models for archaeology lies in an energy-information-economic paradigm based on general systems theory “firms” and an understanding of the “thermodynamics” of ecology. Thermodynamic demands of all living systems to exploit matter and energy and information for self-maintenance and growth (replication).

Models cannot cover “culture” (the idiom). We can model the technologies of production, distribution, consumption and storage. We can create models of adaptive strategies by modeling economic firms in relation to physical, biotic and cultural variables within a time sensitive population density. We can model the existing technological paradigm for production, distribution, consumption and storage systems.

Note that the models above are based on economic/adaptive variables. Change can come anywhere. It can be a matter of changes in the exploitative strategy and exploitative technology of production, distribution, consumption, or storage as part of the economic system in relation to variables in all three environmental sub-systems. It can come from a mix of any of these variables. It can come from changes in the cultural sub-system as well through manipulation of the cultural idiom. It can come from how cooperating human beings access and control valued resources.

Because humans can change, in fact, cannot help but change, and because human groups grow/expand (the normal process of all living systems), the cumulative body of change

results in increased carrying capacity, increased levels of technology, and increased complexity of all types. This cumulative, noisy, sporadic and difficult to predict (specific variables) chaos does result in an overall trend towards increased complexity that we call human adaptation and cultural evolution. Change is complex and is constantly changing. No change is ever a change unto itself. Any change affects in some way every variable in a system, some more than others.

There is a technology of production tied up in a complex cultural idiom. There is a technology of distribution also tied to its idiom. There is a technology of consumption, again with its social idiom. There is a technology of storage, with its idiom. There is an idiom of investment. Production, distribution, consumption and storage are tied to physical resources and their idioms, biotic resources and their idioms, and cooperating as well as non-cooperating human resources and their cultural idioms. Any and all of these variables are subject to change (as a process) for access to, and control over, valued resources as a technology of exploitation and its related cultural idiom.

All of these complex variables are subject to mutual causal processes from feedback in non-linear convolutions impossible to predict or constrain. But since population growth is one key driver, and since systems can change to increase carrying capacity through technological change (and I include culture as a technology), there is a multi-linear drift towards larger, more technologically complex human systems over time.

The only thing that is certain is that overall populations on the earth have grown, and that groups constantly juggle the complex variables in all three sub-environments through a cultural filter rich in symbols and designed to be flexible. Group discussions constantly redefine relationships and interpretations in access to, and control over, valued resources. Vague symbolic terms allow diversity and reinterpretation under changing circumstances, demands and needs.

Complex systems are non-linear by nature and increasing complexity leads to increasing non-linear pathways with unpredictable outcomes. Culture is thus a dependent phenomenon of this manipulation and is isomorphic to the demands of living systems and the thermodynamic process. It operates as a filter between human beings and human groups. It contains latent values connected to matter, energy and information and access to, and control over, resources.

It is possible to create computer simulations of cultural systems. More complex models, however, increase the chance that the outcomes will not predict the real world process. Greater numbers of variable in a non-linear feedback system increase the chance for new and unpredictable outcomes. But with modularity comes an increasing chance at convergence. Each sub-unit has a large number of choices but choice in one is constrained by statistical choice in the others.

Ethnography describes and records culture and its patterns or traits. Ethnographers create summaries for thousands of individual decisions to characterize a cultural system. The results are an interpretation of a period of time for a specific group under general circumstance. An ethnographic study is a kind of “statistical” summation by the ethnographer, and different ethnographers may have come up with variations or quite different reports.

Computer simulations must also be models, and models must be simplified versions of real world processes. Models are only as good as their connection with phenomenal reality. The more complex the system, the sooner the model will diverge from real outcomes. Just look at any weather forecast program. Small differences quickly diverge in non-lineal feedback arrays.

Modular structure based on socio-economic firms is my suggested way to model human society. I am convinced it is possible to develop simulation models for described ethnographic cultures and to model artificial societies through this modular approach.

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# MODULARNI PRISTUP RAČUNALNOM MODELIRANJU SUSTAVA KULTURE: KULTURA KAO TERMODINAMIČKI STROJ

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## SAŽETAK

Kultura je kompleksni nelinearni sustav. Za računalno modeliranje sustava kulture potrebno ga je razdijeliti na podsustave. Ljudska kultura je modularna. Sastoji se od skupa ljudi koji pripadaju ekonomskim jedinicama. Pristup i kontrola materije, energije i informacije postulirani su kao ključni za razvoj simulacija kulture. Budući da su resursi u stvarnom svijetu sklopljeni, navedeni pristup i kontrola iskazuju se u dva povezana područja: ekonomskom (izravna kontrola) i političkom (neizravna kontrola). Optimalni način stvaranja modula za kulturnu ekologiju i ekonomiju slijedi iz paradigme energije-informacije-ekonomije opće teorije sustava kao i iz razumijevanja „termodinamike“ ekologije odnosno razumijevanja kulture kao termodinamičkog stroja.

## KLJUČNE RIJEČI

kulturna ekologija, termodinamika, teorija sustava

# SOCIAL BEHAVIOUR AND THE SUPERORGANISM: IMPLICATIONS FOR DISEASE AND STABILITY IN COMPLEX ANIMAL SOCIETIES AND COLONY COLLAPSE DISORDER IN HONEYBEES

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## ABSTRACT

Sociability, mass response to threat, food production and food sharing and an adaptable communication system are a suite of traits involved in the evolution of complex society in animals. Cycles of interaction characterize members of such societies and those of species in association that can affect disease structure in time and virulence. Colony Collapse Disorder (in North America, Honey Bee Depopulation Syndrome, or HBDS elsewhere) shows similarity to a number of mass behavioural responses in other social animals, especially in ants. A number of questions regarding the cause of CCD continues to make progress in fighting the disease difficult. Here information is provided that may result in an isolation of factors to identify the syndrome of effects that lead to the disease, based on studies of disease avoidance and illness behaviour in other animal species. Most of the work to date to discover a cause has focused on a direct relationship between a pathogen or parasite or environmental condition and the Disorder. Dysfunctional mass behaviour is even seen in humans, as during the Black Plague. Disease avoidance is an important survival tactic for many animals and if the mechanism is modified by a pathogen or toxin unusual outcomes may result. In complex animal societies the opportunity for other forms of disruption of social life are numerous.

## KEY WORDS

colony collapse disorder, complex animal societies, disease avoidance, illness and behaviour

## CLASSIFICATION

JEL: I12, I31

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## INTRODUCTION

Avoiding disease certainly has value to the individual in escaping pain, suffering and death. It would seem obvious that mechanisms would evolve to enhance the ability of an individual to recognize and avoid contact leading to infection or exposure to infection. Social animals especially display evidence of behaviour that avoid or limit disease and death, as in the grouped behaviour of the water flea Daphnia where grouped animals give off more carbon dioxide than single ones and this extra CO<sub>2</sub> can neutralize some toxic substances in the water [1].

It is clear from animal research in the wild and captivity that behaviour can play a significant role in infection and the spread of disease and the production of mortality [2]. Such behaviour would then have a selective role to play in evolution, as Allee argues [1] concerning Cryptocerus, the wood-eating cockroach. These insects can only feed on wood with the aid of wood-digesting protozoans in their alimentary tract. Transmission of these protozoans can only take place in a social context and Allee proposed that as termites evolved from a common ancestor of cockroach and rely on a flagellate protozoan for wood digestion, the foundations of the social situation can be seen as essential for survival. The balance of pathogens or parasites or the lack of a factor they produce for daily life and mean the end of the social context. The same problem may be involved in CCD, and the abnormal behaviour of the bees not a matter of a new pathogen, but a change in the host-parasite relationship, for example, a lack of a factor a pathogen once produced or a change in its chemical make up.

Hart [3, 4] has documented a variety of behaviours that can be described as sanitary, preventing the spread of infection among animals. Bees engage in a number of behaviours that clean the hive, these can be affected by disease. Sanitary behaviours in humans are often integrated in rites, but new disease avoidance behaviour can become ritualized or codified as threats of serious disease consequences are demonstrated, as in the Black Death and the development of quarantine [5]. Douglas [6] found that in studying the varieties of human religious practice, pollution and danger were often associated with a positive effort to organize the environment.

Threats derived from the 9/11 attacks resulted in mass responses to avoidance of disease by taking medications [7]. The appearance of a new and deadly strain of coronavirus in China and Hong Kong resulted in a variety of mass behaviour including wearing masks, fleeing urban centers and contact with crowds [8] paralleling responses seen during the 1918-1919 flu. Images in the world press, for example, the Financial Times (January 12, 2006), show government workers spraying cars to prevent the spread of bird flu at frontier posts. A deluge of “precautionary 77 measures” are recommended in the early stages of perceived serious pandemics, as the refusal to shake hands with a chicken farmer (Christopher Caldwell, in the Financial Times 15 January 2006), the avoidance of perceived gay waiters during the 1990s all seem familiar from past experience. In 2004 MRSA or drug-resistant Staph (Staphylococcus aureus) was found to be infecting healthy people [9] and by early 2008 was recognized as a new public health problem no longer confined to hospitals [10]. Avoidance of touching others, wearing masks and washing hands has recently been stressed during the H1N1 flu.

A number of scientists have written on the potential transformations of society by war [11] and disease [12]. It is the change in the survivors that matters in death and illness whether their reflection on life produces any change in social institutions or behaviour. Influence of the social environment has significant effects on the individual in other species, for example, in bees. Amos Ives Root noted the fact that hives bees who become infected or ill will leave the hive to die alone, published in his studies of the bee in 1879 as *The A B C of Bee Culture*.

Whether instinctual or a socially reinforced altruism, this act of a highly social animal is remarkable, especially in the context of the new disease, Colony Collapse Disorder, where the immature nurses of the bee hive have been found to abandon the hive before they are prepared, perhaps in response to a disease agent [13].

Recent research has shown that human population diversity is distributed by the effects of climate, pathogens and habitat diversity [14]. Also, Guegan [15] found that human fertility increases with the diversity and structure of disease types. The human immune system as it shares features such as innate immunity with insects [16] and others with early vertebrates [17], is much older than our species, yet it shows a remarkable degree of diversity which predates our Neolithic population explosion and the transition of humans to large populations living in dense, sedentary groups [18]. Some biologists have proposed theories of the evolution of social systems based on patterns of selection [19-21].

The pattern of selection that would produce complex social animals capable of building structures (humans, bees, ants, perhaps termites), but also produce food (humans, bees and ants) is rare in evolution. The fact that both humans and ants have domesticated both plants and animals for food production is also rare [20]. That humans and bees have developed complex communication systems capable of considerable plasticity is not found in other complex social animals given our present sensitivity in analyzing ant communication [22]. However, communication by food (trophallaxis) is poorly understood and may provide an insight into communication and order in ant species [23]. An interesting parallel in the fossil record concerning the evolution of ant complex society and that of humans is the correlation of the appearance of both during climatic optimums, the ant's origin of fungus-growing coincides with the early Eocene climatic optimum of about 50-55 mya [24] and human food production and domestication appears during the Holocene Climatic Optimum [25, 26].

To avoid catching a disease, many human societies have evolved standardized behaviours [27]. These behaviours, which are, at times, neither prescribed nor sanctioned, may be ritualistic, stereotyped or taken to extremes by individuals [28]. Understanding human responses to disease has many important applications to public health, as well as to the individual. Such a study can help answer questions such as "How does individual behaviour affect the transmission of infectious disease?" While epidemiological study has resulted in techniques to control transmission and to identify patterns of disease transmission, the cross-cultural and historical study of the psychology of disease transmission has seldom been attempted.

Other questions than may be answered include: "How dependent is disease avoidance on culture?" and "What types of intervention can best be assumed to influence behaviour, affect transmission and increase aid to the infected?" The nature of human consciousness and its reactivity, is a major issue in social science research that can be addressed in this inquiry. For while it is logical to assume that avoiding disease might be destructive to social bonds and association, another aspect of this stress could be of a unifying nature – the origins of the structure of the kind of human social behaviour whose root some theorists like Fabrega [29] have argued lies in the mutual aid extended to the sick and injured. He points out [5] that the cultural definitions of the sick role also pattern withdrawal of the person identified as ill as well as avoidance by those defined as well.

It is clear from reports in several cultures, European in the 14<sup>th</sup> Century [30], the Near East in the 14<sup>th</sup> [12] and China in the 20<sup>th</sup> [31, 32] that the plague has had the ability to disrupt society and affect both commerce and religious practices significantly. Mass behaviour is reported with thousands of individuals travelling together over the countryside while in other cases people often fled from disease singly, while cases of aid and organized care are also

typical during the Black Plague [30]. The power of this disease parallels some others in history as in the Plague of Athens in the 5th Century B.C.E. [33]. In Egypt Dols' [12] sources for the 14<sup>th</sup> Century report a substantial disruption in religious practice, but as the data here show a marked distinction with Europe in mass behaviour, there was little fleeing and no mass psychogenic events (MPEs). MPEs are also termed by psychologists epidemic hysteria (EH) and mass psychogenic illness/mass sociogenic illness [34]. This avoids the ends and means determination, for example is participation in a lynch mob an illness, in a charge in the army or a culturally defined chaotic behaviour (Dionysian rite) illness?

It seems that there must be a balance in behavioural response to disease by infection, between immediacy of action to avoid contact versus plasticity to assess danger. Instinct might provide various stimuli as signals or thresholds to response. Certainly cultural patterns can provide some foundation for these polar alternatives, based on embedded coding of ancient experience with disease as Mead has argued [35], and as we have seen with disaster events as in the case of the Andaman Islanders and the recent tsunami [36]. With regard to instinct, hygienic bees versus non-hygienic [37] do not seem to have fared any better in the challenge of Colony Collapse Disorder [38, 39]. Thus a behavioural system to avoid diseased or potentially diseased nest mates does not provide the level of hygiene or isolation necessary in every case of infection. Since pandemic disease is a characteristic of the late period of human adaptation to sedentary behaviour associated with populations dependent on massive food production, distribution and storage as well as increased population density, we might expect we are in the process of adaption to these conditions. Pandemic diseases have evolved in waves as Zinsser argued [40], mainly Black Plague, small pox, cholera, typhoid, flu, polio, AIDS. The last four have become endemic, perhaps with cancer if it can be separated from general ageing disease.

What is curious about CCD in bees is that bees have long been adapted as sedentary, densely populated food producers, why now do we see them susceptible to such a virulent pandemic? Most bees are not social, or live in socially constructed structures [41]. One argument might be that they have become domesticated human subjects and that recently they have been forced into mass production concentration of mobilized pollinators for agribusiness. Although there is no direct evidence linking this last innovation with CCD changes in lifestyle can produce stress and biological responses as disease. On the other hand, there is an analogy in an ant species that may provide a link and since ants are not domesticated animals we might find a clue to CCD and to modern human pandemic diseases not in only pathogens, but in stress patterns.

Even the course of this complexity and domestication is uncertain. Our knowledge of the evolution of complex societies among other animals, for example the insects, shows us that complexity is reversible. Research with various solitary insects has found that reversals from complexity back to solitary behaviour have occurred at least twelve times [42]. The ants, termites and corbiculate bees that are highly social with complex behaviour are from the Cretaceous period and their closely related solitary taxa have long been extinct. Varying degrees of complex social behaviour are found in wasps and Halictid bees and allow for comparative study.

Various philosophers and scientists have put forth proposals where the basis of human solidarity lies in similar scenarios, for example, where social displays are "epidietic" serving as feedback to adjust or restore the balance between population density and consumable resources [43] through processes of group selection [19] and cooperation [44], others have produced more comprehensive, but elusive explanations, such as forms of social effervescence [45] and mass bonding which is thought to be the foundation of complex society [46]. Nevertheless, even these seem to have parallels in animal societies, as when

Wilson gives examples [20] of behavioural scaling in animal societies where the social organization specific to one species can change dramatically given changes in climate, season, daylight, or other factors. We see this same process in humans as in the case of the Prophet Cults and millenarian movements of Melanesia [47]. What is important to reflect on here is that a typical social organization based on ritual warfare between adjacent groups that was long established was transformed into mass organization based on cooperation to oppose European pressure. Gaius Julius Caesar noted the same phenomenon when he opposed the tribes of Gaul in the first century B.C.E [48].

Speculation on the cause of Colony Collapse Disorder (CCD) in bees has grown considerably in the past few years as the disease has spread in the bee populations and across continents [49, 50]. Characteristics of this disease include the abandonment of colonies and the apparent disorientation and death of individual members. There is some variation in the expression of this disorder and the conditions of its appearance [39]. While it has long been known that members of eusocial bee species cannot survive long without contact with their hive social environment [51], certain definite pathological conditions have been associated with the individual deaths of CCD that differ from separation deaths found under other situations [49, 50].

The broad nature of the process of abandonment and the pattern of individual disorientation and death of the bees in CCD seems quite similar to a disease described as Lomechusamania [51]. This syndrome was unique in the scientific literature of the late 20<sup>th</sup> century and was found in ant colonies. Chavin described a feature of ant behaviour in a certain context regarding the mutualist beetle from contemporary research including that of Pierre-Paul Grasse and Wassman (see [52]). While Grasse's full report was never made available in English it provides another example of mass behaviour induced in a highly social species, while it parallels the work of Wassman and Forel [53] with *Lomechusa strumosa*. Like *L. strumosa*, *Dinarda* a commensal that also inhabits nests of ants, is a beneficial scavenger of mites that attack the ants. It also eats the dead bodies of ants and nymphs preventing the growth of mold. *Lomechusa*, unlike *Dinarda*, has no beneficial effect but by its presence "drugs" the ants with a substance and survives off the food of the ants. Another commensual, *Atemeles* also feeds off the ants and is tolerated but has no beneficial effect. In fact, there is evidence they and *Lomechusa* affect the nest production resulting in a type of adult called a pseudogyno, a form of ant that works less in Forel's experiments [52], has a smaller brain and is sterile. The substance *Atemeles* gives off to placate or stupefy the ants can result in destructive behaviour in some cases, as one reported by Forel [52] where *F. fusca* nest members licked its body for the exuded substance so furiously they eventually caused wounds and then at times this led to its being eaten. While many act species have structured behaviour that acts to quarantine foreign species, these commensals have adapted means to overcome this protective behaviour.

Here we can see a process of acceptance derived from defense. In one case Forel [52] describes how an *L. strumosa* entered the nest of *F. rufibarbis* and was immediately quarantined in a violent attack by *F. rufibarbis* who drench it with poison which caused the *L. strumosa* to respond with gaseous exudations. This exchange seemed to create a context for acceptance as the *F. rufibarbis* came to eventually start licking the *L. strumosa* and it became integrated socially. Humans have been using quarantine since it was invented in Venice in the 14<sup>th</sup> century during the Black Plague. It is often effective, but can cause social disorder and resistance as seen recently during the most recent Ebola epidemic.

A main difference in nest behaviour between ants, termites and bees is that ants and termites often share their nests with commensals [51]. One source describes the relation between the

Lomechusa beetle and ants as “commensal” [51] but it seems to be more parasitic, although another authority does not use this term [54]. The Lomechusa beetle lays its eggs among the ant brood. The Lomechusa grub is fed and can eat the ant brood as well. It utilizes a number of chemical signals to communicate or influence the behaviour of *Formica sanguinea* [51-53]. If attacked, the beetle displays its trichome hairs which the ant licks with relish. This is a way there is a transfer of substance from the beetle to the ant. Affected ants lose their usual behaviour, neglect the brood and abandon the nest.

Heinze and Walter have reported [55] experimental results that seem to confirm Grasse’s work. Ants exposed to the fungus *Metarhizium anisopliae* left their colony hours or days before death and away from nestmates. They also observed worker ants dying from other causes than disease leaving the nest. To test for the effects of the fungus on ant behaviour they used CO<sub>2</sub> and the vast majority exposed who survived left the nest before death.

Recently a pathogen, *Nosema ceranae*, was found to be the causative agent in some European apiaries and treatment of these apiaries to destroy this pathogen arrested the disease [56-58]. While it seems unlikely that this pathogen is responsible for all forms of CCD in all locations as it has been found in many non-CCD colonies [49], it is a welcome development and now study of the etiology of disease and the CCD behavioural consequences can be investigated. *Nosema* was also found in many CCD colonies in association with invertebrate iridescent virus strains (IIV) [56-58], but there is no explanation of how these pathogens could cause the features of the disease. It is assumed that all bees that do not return to the hive have expired due to the physiological degradation caused by *Nosema ceranae*, IIV or a combination of them. Investigations of bees found in CCD hives show distinct variation from *Nosema ceranae* infection or lack of it [50]. However, the spores of *Nosema ceranae* may have an effect on bees in addition to the pathological degradation, producing also an allergenic effect or behavioural modification. Bailey theorized [59, 60] that fungal infection might increase due to faecal contamination within colonies as it becomes “... greatest by the end of winter when bees have been confined for the longest period and is cleared away in summer in undisturbed colonies by the several generations of nest-cleaning bees that ingest any contamination and void their faeces in flight away from the colony.” Therefore a behavioural change that limited cleaning could increase fungal exposure and lead to levels of infection that would overcome a colony. Leaf-cutting ants have specialized workers who remove waste and corpse from the nest. Heinze and Walter propose [55] that species with smaller colonies can leave a nest easily without contaminating other nest mates, while in larger colonies specialized waste collecting workers function to effectively remove moribund ants from the more complex situations.

## **OBSERVATIONS AND AVOIDANCE BEHAVIOUR**

Recent studies of the bee genome [61] have shown that they have few genes that regulate their immune system and this may be why they are subject to other devastating hive infections. The behaviour where individuals avoid the hive if ill or damaged would also go far to prevent general epidemics. One might argue then that in bees, avoidance behaviour is an important adjunct to immune system response and has acted in tandem with immune system gene selection in the evolution of complex social evolution. This hypothesis would fit with what proposed Loehle [2]. Avoidance surveillance would be particularly important in light of the fact that bees use pheromones to differentiate kin and outsiders. Mass induced behaviour by disease has been considered for over 100 years in humans, especially regarding remarkable examples from the Black Plague of the 14<sup>th</sup> century C.E. and other forms of stereotyped disease avoidance customs have been noted by several researchers (1951-1961). This is particularly interesting in the context of Cremer & Sixt review [62] of the analogies in

the evolution of individual and social immunity. A successful response to infection requires identification of pathogen and an appropriate response at both the level of the individual in a biological immune response and a socially defensive behavioural response. These are both intertwined with the evolution of pathogen genomic variation to elude both responses.

Stimulation of distinct behaviour patterns has been long studied by ethologists. The work of Tinbergen [63] among others established the general principles of the field. The survival of individuals in threatening conditions by stereotyped responses to particular chemical stimuli has become a rigorous field of investigation with improved instrumentation to detect trace residues in the past few decades. For example, the presence of trimethylthiazoline (TMT) a component of fox feces was found to elicit freezing in rats, a prominent behavioural sign of fear [64]. A new discipline has grown up in the past thirty years that has focused its attention on social behaviours influenced by selection for pathogen avoidance [2]. Many animals, especially Hymenoptera expend considerable energy removing foreign objects from their nests, such behaviour could have infection reducing results, and similar sanitary actions have been documented in other animals [2-4, 65, 66]. However, viral interaction of interference with gene expression for hive behaviour could also be a causative factor in CCD, as it has been found that a single gene is centrally involved in hive sociability [61].

However, the fact that infection in CCD can be transmitted by the reuse of equipment from CCD colonies and that irradiation of such equipment can eliminate transmission [49] suggests a specific causation that is similar to Lomechusamania. Seminal studies in the denaturing of proteins by ionizing radiation began with work by Fricke [67] in the 1950s, since it was assumed that a substance is transmitted from the beetle to the ant in Lomechusamania, a similar substance that could induce CCD might be denatured by irradiation.

The production of social barriers to the spread of disease has been noted as a peculiar, but not infrequent aspect of eusocial animals [68, 69]. It has also been noted that behaviour and chemical signals of sick animals can produce stereotyped responses from healthy ones [2]. Three general trends can be identified that are of interest in eusocial animals and CCD: 1. location avoidance due to sensing of chemical signals of pathogens or danger, 2. avoidance of individuals or herds due to signals indicating illness and 3. sensing illness in other conspecifics and in self. Interruption of any of these response bases could explain the etiology of CCD in bees. It would also explain the lack of a uniform set of symptoms and pathological expression of disease state from colony to colony. A stimulus that induced a malfunction in surveillance could produce a general colony avoidance. Recent research in honey bees and discovered a negative feedback signal that can reduce recruitment [70]. Panic in humans is often induced through language such as honeybees communicate with a language that is not only versatile in modifying detail [71] and allows for individual adaptation in learning different languages [72] but is similarly distorted by drugs [73] as in human language we might consider the role of a specific negative feedback pathology.

Location avoidance is common in many insects where pheromones are deposited to mark territory and can elicit aversive or aggressive behaviour, for example in *Oecophylla longinoda* [74]. Some animals' behaviour is changed in specific ways to suit a parasite's fitness as in fungal infection of millipedes and ants [75, 76]. This is an example of disease diverted behaviour (DDB). Research into specific pathways of DDB has recently focused on a number of mechanisms in infection, for example, inflammation [77] and is referred to as "sickness behaviour" in humans. Heinze and Walter have already shown [55] that this is not the case with their ant behaviour. Many vertebrates are affected in quite similar fashion behaviourally by infection with prion disease. A degradation of normal behaviour takes place

resulting in purposeless sequences and wasting [78-80]. Since there are behavioural aspects of bee hygiene, as in the case of nest cleaning differences between strains, such behaviour can have a substantial effect on colony survival [37].

Along this line of investigation, Core et al. have demonstrated [81] that the parasitic phorid fly *Apocephalus borealis* can induce hive abandonment behaviour in honey bees. While this cannot explain every example of CCD nor bee die-offs, it fits the pattern of behaviour modification by infection resulting in avoidance I have described.

I am not suggesting that Lomechusamania (or the Heinze & Walter effect) and CCD/HBDS are the same syndrome, rather that they may proceed from similar pathways of causation. A Lomechusamania/ CCD could be induced by either a parasite as in the case of Nosema or varroa infections or Israeli Acute Paralytic Virus (IAPV) together with some other stress or co-factor as in some human disease conditions [82]. The fact that IAPV seems the best candidate due to time association and presence of disease would argue for IAPV to be the productive agent [49]. Interestingly we find that fungal prions act to induce invader fungus to die in certain cases acting like stress induced apoptosis in cellular death. Usually cascading stimuli are the triggers with no one source as an identified initiator. CCD could therefore be seen as an environmentally induced mass behavioural dysfunction, like Lomechusamania in pattern but taking different temporal form and structure due to different conditions and genetic variation. It is evident that the effect of the environment and genotype interaction can produce significant variation in pathogenicity in host-parasite interaction [83]. One obvious character would be the rhabdomeres of the eye that allow for the bee to “see” polarized light. In experiments conducted by von Frisch [84] blocking of the transmission of polarized light resulted in confusion and random behaviour in the bees so exposed.

Similarities between Lomechusamania and CCD center on the abandonment of the hive or nest by adults, random behaviour of the afflicted individuals, excess brood present relative to adult bees. However, the Lomechusa beetle (*Lomechusa strumosa*) has developed a mimic behavioural regime that allows it to be fed by the nursery ants of *Formica sanguinea* (Europe) [54]. Published research on the Lomechusa beetle is quite limited and should be extended to better characterize the relationships between beetle and ant especially how each responds to specific situations, for example, inside the nest in familiar conditions of interaction and outside where potentially hostile contact can occur.

Fruitful research might be directed to specific genetic sequences that might identify similar triggers in ants and bees to substances involved in parasite presence or environmental triggers. Another likely source could be related to the considerable taste and smell abilities of the bee, known now for almost 100 years [84]. Or epigenetic interactions on aspects of sociability, as in the genetic interaction that produces nest cleaning [85, 86]. There are a number of pathways that have been found in other animals to affect epigenetic expression of complex gene interactions [85, 87, 88]. Silencing of expression of DNA methyltransferase Dnmt3 results in changes in developmental outcomes and behavioural status in bees [89].

## **CONCLUSIONS**

Some chemicals have been found to affect the behaviour of vertebrates in uniform ways [90] while epigenetic effects have been implicated in disease differences in human twins [91], epigenetic changes are also associated with aging [92] and the onset of characteristics of senescence could be a pathway to explain CCD in bees along with the production of other disease mimicking states induced in different genomes of bee populations. It is known from experiments von Frisch [93] conducted over half a century ago that under stress bees can

change their stage of development and re-develop organs necessary for colony survival, like salivary glands. These are probably influenced by epigenetic pathways and may be susceptible to pathogenic changes.

The accumulation of melanin [59, 60] is associated with aging and has been found in many bees in hives subject to CCD [50]. Epigenetic variations may be spreading through bee populations by several environmental stresses (risk factors). Like AIDS in humans, there may be one underlying causative agent. Melanosis another distinct disease condition [59, 60] has been found in many bees, has have a number of pathogens in like manner to the spectrum of pathogens found in early AIDS patients. Also, as in AIDS in humans, the expression of CCD may be masked by genetic differences in populations, in differences in different behaviours (risk factors) that promote the spread of the agent, and a variety of factors that make bee populations susceptible to infection and disease progression [94]. This scenario seems most likely when we consider the report by Higes et al. [56] and others [57, 58] where a variety of pathogens are found in the two populations studied, but an absence of Israeli acute paralysis virus (IAPV) and low numbers of Varroa, no agricultural pesticides but the presence of acaricides but with infestation by *N. ceranae*. Treatment with fumagillin resulted in survival of the colonies, absence of CCD symptoms and elimination of *N. ceranae*. The fact that *N. ceranae* is found in many colonies where CCD has not developed [49] supports the idea of multiple factors including genetics as does the fact that *N. ceranae* was present in the infected colonies with acaricides reported by Higes et al. [56]. The relation of pesticides in CCD may be indirect but at present is unproven. A Chinese case from Sichuan Province seems to implicate pesticides where bees have been eliminated due to over spraying. However, this may not be related to CCD [95].

Modeling the epidemiology of the cases of disease helped to identify AIDS as a disease complex, characterizing the different factors associated with its different disease states and expression (e.g., slow responders, susceptible gene variants, quasi-species of virus) [94]. CCD may be controlled in a similar effort. It should be kept in mind that this recent phenomenon has taken place in the context of a substantial decline in native wild bees in North America and Europe since the mid 1900s [96].

Whether it is Lomechusamania, CCD or AIDS, it is obvious that the sedentary conditions of complex life for animal societies makes them liable to infectious disease that can induce behavioural correlates. In the evolution of human societies a number of diseases have become severe challenges to complex sedentary life, some of these have abated by genetic change and selection, e.g. the Black Plague, others by human response, like small pox. Human response is paralleled in bees by nest-cleaning varieties. Since there have been some reversals in social complexity in a number of insect species, and temporary ones in human history (e.g. after the Black Plague), it seems likely that disease, and especially epidemic infectious disease would be a likely agency for reversals. Humans would be especially liable to reversals in the past given the reliance on learning and memory and the potential loss of knowledge should elder cohorts of populations be lost in pre-literate groups. It is obvious that bee evolution is continuous, but what is unclear are the possibilities for increased complexity and plasticity in social bees. The implications for human social evolution are obvious as well, what are the prospects of what has been considered “stable” societies in human history given that contemporary capitalism is characterized by continuous destructive evolution [97]. Are bee, ant and termite societies “closed” in the sense that they have reached a limit of complexity given their behavioural capacity or are they representations of stable complexity? Waddington argued [98] that “...types of instability have been built into the epigenetic mechanisms by selection for response to environmental stresses.” Humans seem capable, on

the other hand, to respond in a rather Lamarkian fashion to environmental changes but some authors have concluded that corrective responses are unlikely given the recent human past [99]. Other students of world systems research like Chew [100] see a revitalizing role for periodic instability and collapse of human social complexity. Perhaps we are too close to the evolution of complexity to be able to have the proper perspective to assess possible mechanisms of corrective change [101], or as Mead argued [35], we have not produced the necessary social science tools to discern the elements of such change and how to manipulate them. One example is in memory or knowledge transmitted over time. In ants it has long been known that pheromone traits “lead” colony ants to goals, but recent studies have demonstrated that the information encoded in the trails is complex and the trails are now referred to as part of the ant’s “external memory” system [102]. Humans also could be said to have such systems in urban road signs, advertisements, or in simple form in some traditional societies in “message sticks” that are set along trails telling later passersby how long ago the individual passed that point, where the moon was, whether there was food or game available, etc.

Recent research in ant societies has perceived these colonies as “superorganisms” and that the nature of the society has significant effects on the longevity of the colony and its individual members. Shik et al., found [103] that small colonies have shorter duration than larger ones and that this is mirrored in the shorter life spans of smaller colonies. Can we view human societies in a similar fashion, does this hint to patterns of survival in village life that determine shorter lives than those in human settings? The concept of the superorganism is not new, Wheeler proposed it in 1911, but the effects of selection in molding the nature of a society’s members [104] has significant implications for our understanding of the evolution of complex societies. Social insects, often referred to as “eusocial” and Hou et al. [105] have extended this examination of selection on individuals of colonies and the evolution of complex societies in animals. This idea then results in other possibilities, especially if the selection acts on individuals as it acts on colonies [106]. This creates a central contradiction as we find that in eusocial animals there is a tendency for reduced genetic diversity as single queens produce all colony members at one time in the most successful species. Yet, such a clonal reproduction strategy while it might maximize altruism necessary for eusocial life, reduces the genetic foundations of resistance to disease and pathogen challenge [107].

A number of scientists in the 20<sup>th</sup> century (e.g. [40]) saw a role for disease in the evolution of society. Perhaps we can learn something about how complex societies adapt to disease by studying the behavioural responses of complex animal societies. It does seem apparent, however, that the fragility of complex societies, whether human or other animal, is related to basic factors of reproduction, density and communication. As Wilson has noted [20] most insect complex societies are highly interrelated and they tend to have short lives in either specific social ordering (as in bees) or in location (as in ants). The solution in these examples is different, in bees the colony may survive a year or two but require a new queen and reconstruction of the hive, often also in a new location. With ants there is often a periodic relocation to a new setting. Still, complexity in social insects is often attributed to their ability to choose the sex of their offspring, the ‘haplodiploidy hypothesis.’ Thus complex societies are liable to both genetic exhaustion and environmental degradation. In termites, however, instead of having a predominance of one sex, we find equal numbers of both sexes and yet complex society, this ‘sex-ratio adjustment’ hypothesis’ has largely replaced the ‘haplodiploidy hypothesis’ [108].

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## DRUŠTVENO PONAŠANJE I SUPERORGANIZAM: POSLJEDICE NA ZARAZE I STABILNOST KOMPLEKSNIH ŽIVOTINJSKIH DRUŠTAVA I KOLAPS KOLONIJE PČELA

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### SAŽETAK

Društvenost, masovni odgovor na prijetnje, proizvodnja i dijeljenje hrane te adaptivni komunikacijski sustav predstavljaju kolekciju svojstava uključenih u evoluciju kompleksnih životinjskih društava. Ciklusi međudjelovanja, koji mogu utjecati na strukturu i podložnost zarazi, karakteristika su članova takvih društava kao i pripadnih vrsta. Poremećaj kolapsa kolonije (naziv korišten u Sjevernoj Americi za pojavu koja se drugdje naziva sindrom depopulacije pčela) sličan je brojnim masovnim ponašanjima drugih društvenih životinja, posebno mrava. Niz pitanja o uzroku poremećaju kolapsa kolonije otežava napredak u borbi protiv zaraza. U ovom radu razmatraju se informacije, koje mogu dovesti do izdvajanja faktora za identifikaciju znakova učinaka koji dovode do zaraze, dobivene na temelju istraživanja ponašanja izbjegavanja zaraze i bolesti kod životinjskih vrsta. Većina dosadašnjih istraživanja uzroka fokusirala se na izravnu vezu između poremećaja s jedne strane i patogena, parazita ili uvjeta okoline s druge strane. Disfunkcionalno masovno ponašanje vidljivo je i kod ljudi, kao tijekom epidemija kuge. Izbjegavanje zaraze značajna je taktika za preživljavanje mnogih životinja. Ako se mehanizmi taktika modifiraju patogenom ili toksinom mogu se javiti neuobičajeni ishodi. U kompleksnim životinjskim društvima brojne su mogućnosti za druge oblike remećenja društvenog života.

### KLJUČNE RIJEČI

kolaps kolonije, kompleksna životinska društva, izbjegavanje zaraze, bolest i ponašanje

# ORGANIZING FOR EMERGENCIES – ISSUES IN WILDFIRE FIGHTING IN CROATIA

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## ABSTRACT

Croatia's accession to the European Union implies inevitable changes in the national emergency management system. New requirements for adjustment in accordance with the EU standards and practices also apply to the fire-services organization. Harmonious functioning of a large number of relatively autonomous organizations related to the National Protection and Rescue Directorate necessitates clear decision-making authority and coordination mechanisms as well as a high level of interoperability and core competencies development. This paper gives an overview of the Croatian fire protection organization along with its accompanying legislation, followed by an analysis of identified problems, especially those concerning fighting of wildfire. In our research a survey questionnaire comprised of Likert-scale items was used to assess the attitudes and experiences of trained fire department members. The respondents reported a relatively low evaluation of effectiveness and appropriateness of the following key fire service attributes: organizational structure, legislation and firefighting logistics support. From the obtained results guidelines can be drawn for possible redesign of the emergency management organization, especially those concerning the fire protection service.

## KEY WORDS

coordination and interoperability, emergency management, firefighting, organizational changes, survey

## CLASSIFICATION

JEL: C38, C83, D80, F52, H59, H76

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## INTRODUCTION

Due to climatic influences and its geomorphological and biological specificities, the Republic of Croatia is particularly exposed to open space fires (or wildfires), especially in the coastal areas. Such a fire can have characteristics of a large fire, which requires the involvement of all the material, technical and organizational resources of associated agencies and the wider community, which can consequently disturb the functioning of certain segments of society. In that respect, the role of firefighting is particularly notable in the improvement of public safety in Croatia.

In the United States, the purpose of Firefighting as Emergency Support Function is defined as providing “Federal support for the detection and suppression of wild-land, rural, and urban fires resulting from, or occurring coincidentally with, an all hazard incident requiring a coordinated national response for assistance” [1]. Emergency management generally needs to ensure an efficient emergency response as a process of gathering resources and acting upon the problems immediately after the incident that may result in damage to property or harm to people occurs [2]. Sylves [3] claims that emergency management can be defined as the process of developing and implementing distinct policies concerned with mitigation, preparedness, response and recovery. The definition of emergency management by Wilson and Oyola-Yemaiel [4] includes coordination of all emergency functions in order to prevent the occurrence of damage and minimize its extent.

In Australia, emergency evacuations generally occur in the face of natural disasters, most commonly in case of wildfires, floods and, occasionally, cyclones [5]. In the European Union, according to Zulean and Prelipcean [6; p.515], the most important factors regarding emergency preparedness and strategic planning include the concerns of a majority of citizens regarding man-made disasters, natural disasters, terrorist attacks and armed conflicts. In the European Union, the firm attitude prevails that activities in the civil protection should be coordinated across the member countries. According to Turoff et al. [7], in a study [8] conducted among the majority of Romanian emergency system managers, large-scale forest fires were identified as a second ranking threat, after earthquakes.

In Croatia, efforts in creating an effective organization that would enable successful *emergency management* led to the establishment of the National Protection and Rescue Directorate (NPRD) in 2005. The European emergency number 112 has been attached to the NPRD [9], which can be used for notifications on situations requiring urgent medical aid, or interventions by firefighters, police, mountain rescue service or other NPRD services.

Upon the establishment of the NPRD in Croatia, certain organizational discrepancies regarding firefighting emerged between that new central institution and the existing Croatian Firefighting Association under the Ministry of Interior. While in some fire emergency situations the system functions properly on the whole, relative redundancy and inconsistency regarding the regulation, management and supervision is generally evident in its functioning. Finally, oscillations can be observed in the organization at the local level, especially in fighting wildfires.

Modern organizational design in emergency systems, including firefighting, is mainly concerned with issues of legislation, institutions, coordination and communication of organizational entities and resource allocation [2, 10-13]. Due to the multi-dimensional character of the issue, a detailed overview will first be presented.

The main objective of this paper is to examine firefighting in Croatia, the accompanying legislation, efficiency of the operational functioning of the organization in emergency response



**Figure 1.** Geographical position of Croatia as a relevant factor in the context of coastal firefighting.

activities as well as potential causes of inefficiency. The availability of human resources with experience in participating in emergency response scenarios enabled us to conduct research (Section 5) into observations and opinions related to operational functioning of firefighting in crisis situations. The results of our research are aimed to indicate possible directions and recommended organizational changes, taking into consideration identified shortcomings.

## **THE FIREFIGHTING SERVICE IN CROATIA**

Organization of the fire service, with a large number of different and relatively autonomous actors, is demanding in terms of both management and coordination. Territorial organizations have a great influence on distribution and delivery of vital resources. In bigger crisis situations, the tasks of planning of operations, deployment and redeployment are particularly challenging. In the context of complex firefighting actions, the term ‘organization’ is of key importance. According to some authors, e.g. [14], it can generally refer to the activity (organizing) or the condition arising from organizing (that is – order, design, system structure). Consequently, the firefighting system must be transformed from its state of readiness into the operational state in a short time, depending on the necessity for an emergency response. The success of this transformation is crucial for the outcome of firefighting actions.

At the beginning of every year, the chief firefighting commander of the Republic of Croatia makes a decision on the establishment of the Croatian Fire Brigade Headquarters, Coastal Firefighting Headquarters, Continental Firefighting Headquarters, County Firefighting Headquarters, and appoints their commanders. The holder of the preparatory activities for the fire service is the NRPD. For the purpose of firefighting actions in two or more counties additional forces can be engaged, such as the firefighting air force and members of national intervention units. In such cases the intervention is managed and coordinated by the Continental Firefighting Headquarters. With regards to emergency management, large fires are recognized as a permanent security risk for the Republic of Croatia in the Security Strategy as a cornerstone document of Croatian security [15]. Wildfires are also defined as a particular threat to lives of citizens and their property in the Regulation on Internal Organization of the NRPD [16].

## **THE LEGAL FRAMEWORK FOR FIREFIGHTING**

Article 135 of the Constitution of the Republic of Croatia stipulates that local authorities perform the activities of local jurisdiction that directly address the needs of citizens, such as firefighting and human protection. The Law on Protection and Rescue, as a cornerstone

document for protection and rescue [17], regulates the system of protection and rescue of people, material and other resources in disasters and catastrophic accidents. Before the Fire Protection Law issued in 2010 [18], legal solutions had been outdated and inconsistent with the current legislation in the Republic of Croatia and the EU law acquires. Specific areas, such as conformity assessment, placing on the market, availability and control of fire protection products, had not been arranged at all. The Law on Protection and Rescue [17], with its sub-regulations and corresponding acts related to this law, almost entirely meet the criteria set in accordance with the EU accession guidelines. The emphasis in the EU regulations is on the decentralization of the firefighting service, an issue which still poses certain challenges in Croatia.

The Fire Protection Law [18] regulates the fire protection system, which includes planning for fire protection, prescribing measures for fire protection of buildings, setting up entities for fire protection, fire protection enforcement, fire protection funding and training as well as accreditation for performing fire protection. The Law on Firefighting [19] primarily defines firefighting activities and bodies involved therein, namely: firefighting units, volunteer firefighting units and firefighting associations. The establishment of firefighting units is the responsibility of representative bodies of the local self-government, in accordance with firefighting protection plans. In addition, volunteer firefighting departments can be established at the local level.

The firefighting system is also additionally regulated by the Occupational Health and Safety Act, in accordance with the National Fire Protection Strategy (Draft) [20]. New laws, sub-regulations and directives for firefighting are issued almost on annual basis, or at least amended in order to comply with the existing legislation and enable proper organizational functioning.

## **INTERNAL ORGANIZATION OF THE NATIONAL PROTECTION AND RESCUE DIRECTORATE**

In Chapter 2 of the US Federal Emergency Management Agency's doctrine document [10] its roles and missions—ranging from preparedness to recovery—are described and explained. Similarly, in Croatia policies related to a whole spectrum of emergency management sub-processes at the national level are defined by the NRPD, while the implementation of activities takes place at the county and local government levels. The NRPD provides the assistance, support and leadership to help the state, county and local governments build operational capabilities needed to successfully implement preparedness strategies. In the selected representative excerpt it is stated that the mission of the NRPD is "... to establish and maintain a modern system of protection and rescue in Croatia that, using all available resources, will be able to respond to needs for the protection of people, property and the environment ..." [21].

An organizational structure is generally a formal system of tasks and relations of authority that serves to exert control of coordination of human activities and the use of resources to achieve organizational goals [22]. The main purpose of the implementation of the management structure is organizational control [23]. According to the government's Regulation on Internal Organization of the NRPD [16], the Headquarters is set up in the capital, with regional (county) offices established for the protection and rescue of a particular county's area. The Headquarters staff is organized in the following units: Office of the Director, Department of International Relations, Internal Audit Department, Civil Protection Service, Firefighting Service, 112 System Service, College of Firefighting and Rescue, and Shared Services. The NRPD mission is defined by the Law on Protection and Rescue and the Law on the Structure of State Administration [24].

The NRPD is an independent professional and administrative organization in charge of preparation, planning, management and coordination of operational forces. The Chief Firefighting Commander, who is also the Assistant Director of the NRPD, is responsible for the organization, training and preparedness of the Croatian firefighting forces. The National operational forces in the structure of the NRPD are the State Firefighting Intervention Unit and the State Civil Protection Intervention Unit. Those operational units are responsible for conducting emergency operations as well as for planning and preparedness. According to several documents e.g. [25], there are three levels in the organization of Civil Protection in Croatia. Fire brigades pertain to Level 3 (that is, town or municipality mayors), while the central authority can exclusively intervene and move units from one area to another.

## CROATIAN FIREFIGHTING ASSOCIATION

The Croatian Firefighting Association (CFA) is a professional, humanitarian and non-political association whose declared mission is to "... act as one of the pillars of public safety with the primary task of ensuring the security of people and property in order to strengthen the national security system through the implementation of firefighting activity" [26]. To achieve such a mission an advanced human resources development system is needed which relies on the education and development of competencies required to perform complex jobs. Therefore, for each particular position general and specific skills requirements are defined in [19] in Article 21.

The head of the CFA is one of the Assistant Chief Firefighting Commander of Croatia. The CFA bodies include the CFA Assembly, Presidency, Operational and Technical Staff and Supervisory Board, among others. The Law on Firefighting [19] defines the bodies responsible for firefighting activities, that is, professional firefighting units, volunteer firefighting units and firefighting associations. Fire intervention units, which are under the direct jurisdiction of the NRPD, are not included in the organizational structure of the CFA. In Croatia there are 20 county firefighting associations together with the Firefighting Association of the City of Zagreb (Table 1), all of which constitute the CFA. The Association receives funding through the state budget, whereas volunteer firefighting associations and other fire-fighting societies are funded by counties and municipalities (with up to 5% of their own revenue).

Table 1 shows that a large ratio of human resources is generally not allocated in the coastal areas, where most severe wildfires tend to occur. Out of the total size of the firefighting force,

**Table 1.** Existing firefighting forces in the Republic of Croatia by counties [27].

County	Coastal area	Number of firefighters		County	Coastal area	Number of firefighters	
		professi- onal	volunteer			professi- onal	volunteer
Bjelovarsko-Bilogorska	no	97	1 870	Primorsko-Goranska	yes	226	1 300
Brodsko-Posavska	no	52	893	Sisačko-Moslavačka	no	103	1 720
Dubrovačko-Neretvanska	yes	150	1 056	Splitsko-Dalmatinska	yes	136	1 510
Istarska	no	226	1 001	Šibensko-Kninska	yes	119	410
Karlovačka	no	72	7 000	Varaždinska	no	69	1 721
Koprivničko-Križevačka	no	109	2 382	Virovitičko-Podravška	no	39	2 400
Krapinsko-Zagorska	no	74	2 980	Vukovarsko-Srijemska	no	83	1 354
Ličko-Senjska	no	50	472	Zadarska	yes	164	1 106
Medimurska	no	37	1 020	Zagrebačka	no	120	4 594
Osječko-Baranjska	no	126	1 940	City of Zagreb	no	337	6 772
Požeško-Slavonska	no	40	2 761	<b>TOTAL</b>		<b>2 429</b>	<b>46 262</b>

professional and volunteer, respectively ( $2\ 429 + 46\ 242$ ), a fairly small portion ( $795 + 5\ 382$ ) is situated in the Croatian coastal counties.

## FIGHTING WILDFIRES: THE CASE OF CROATIA

The Mediterranean region is exposed to wildfire threats that have negative impacts on people and property, and also destroy biodiversity, increase desertification and decrease air quality, among others [28]. Wildfire management can be defined as an activity aimed for protection and rescue of citizens and property from harmful effects [29]. The common and most important task in managing the fighting of wildfire is to adequately and accurately select and mobilize the necessary forces and material resources to successfully combat fire. The major factor that influences the movement dynamics of wildfire is fast-flowing wind [30, 31]. Such wind can create conditions for skip fire, which causes fire to spread across longer distances. In fighting wildfire in Croatia local firefighting units in municipalities on the territory of which the fire occurs are primarily involved. Depending on the degree of vulnerability, which is often defined on a 1-5 scale, additional forces can be engaged.

In Table 2 it is evident that material damage caused by fire in the coastal areas periodically exceeds the damage in the continental areas four times, wherein oscillations in the damage tend to occur more frequently in the coastal areas. The discrepancy between the size of the available firefighting forces (Table 1) and the data presented above is notable. Namely, expert assessment of fire severity and vulnerability indicates a high level of vulnerability in a large part of the coastal areas, with a minor risk level in the continental areas. Some other countries facing similar problems are even starting to consider the inclusion of the tourism industry in the structure of protection and rescue, as reported in [33].

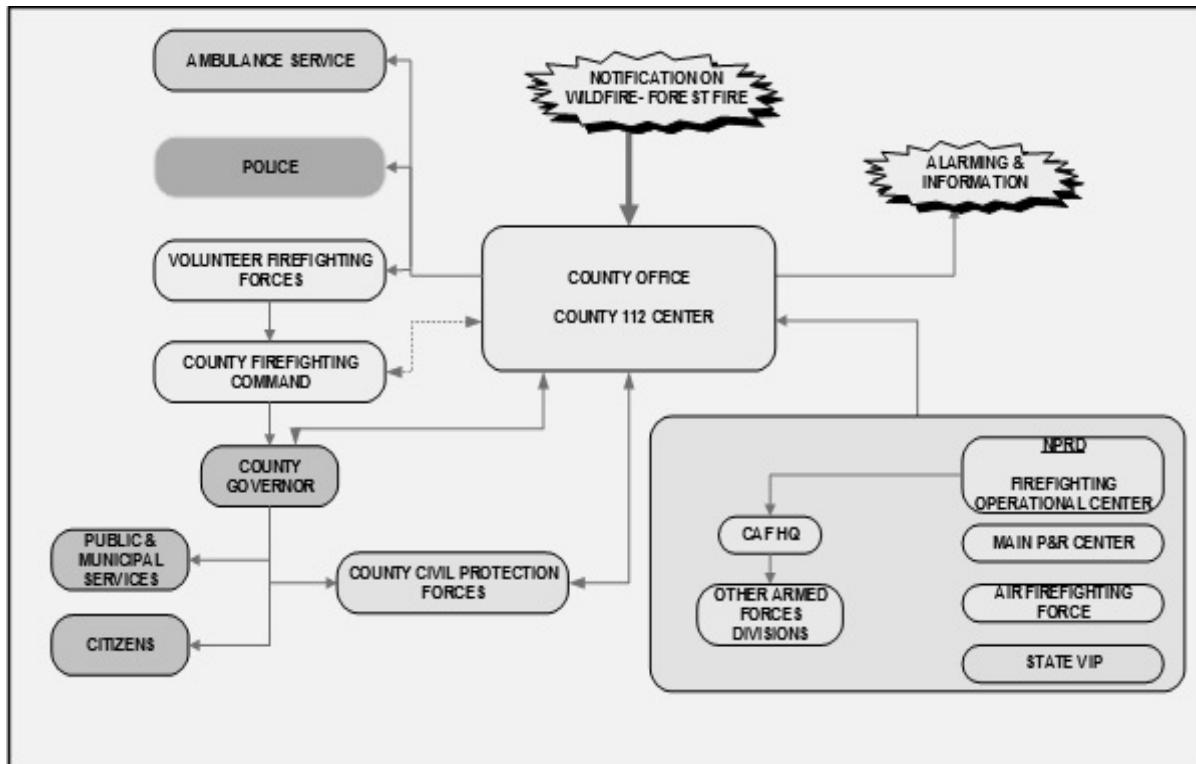
## ORGANIZING WILDFIRE OPERATIONAL ACTIVITIES

According to fire protection plans, in the period from 1 June to 30 September additional troops are engaged in coastal firefighting forces, for which planning of training and equipment is also required.

The Croatian government enacted the Program of activities in the implementation of specific fire protection measures of interest to the Republic of Croatia in 2013 [34]. Based on that program the Plan for dislocation of firefighting forces was developed. Wildfire in a particular area (e.g., a county) commonly requires alarming several firefighting units. In that case the County firefighting commander takes command with the support of the County Firefighting Headquarters in coordination and management of activities. For the purpose of rapid reaction in fighting wildfire, considering the coastal area exposure, State Intervention Firefighting Units Department were founded to which the Air Firefighting Unit of the Ministry of Defense also belongs (Fig. 2). Such a complex organization encompassing different units requires good coordination and communication. The aforementioned challenges in wildfire firefighting

**Table 2.** Material damage in open space areas caused by fire [32].

DAMAGE	2003	2004	2005	2006	2007	2008	2009	2010	2011
MATERIAL DAMAGE OF OPEN SPACE – CONTINENTAL AREA (1000 HRK)									
	124516	20219	31829	44606	238477	115814	38319	10128	91805
MATERIAL DAMAGE OF OPEN SPACE – COASTAL AREA (1000 HRK)									
	1604044	47217	34543	40711	634049	209847	63551	51374	486670
<b>SUM</b>		1728560	67436	66372	85317	872526	325661	101870	61502



**Figure 2.** Schematic representation of coordination of all forces at the county level during forest fire [27].

also indicate the requirements for effective application of a special form of firefighting logistics.

# FIREFIGHTING LOGISTICS AND LOGISTICS MANAGEMENT

As a science, logistics is a collection of multidisciplinary and interdisciplinary knowledge related to exploring and applying laws of planning, organizing, managing and controlling the flow of materials, people, energy and information through organizational systems. In accordance with this definition, the process of logistics management [35] is defined. Recently some authors [36] have suggested that firefighting logistics should be considered as a subsystem of the so-called ‘quintary-logistics system’ of specialized logistics (also including public administration, army, judiciary, etc.). Firefighting logistics as a science and firefighting logistics as an activity refer to the totality of resources, potential, measures for the protection of natural resources, people and their property from fire, especially large fires which cause extreme material damage [37].

Owing to its central role in the emergency response system, the NPDR activity is of key importance for ensuring coordination during major firefighting actions as well as in the strategic planning and procurement of equipment for fire service tasks. Consequently, NPDR is actually responsible for proper firefighting logistics support, which includes: optimal performance of firefighting actions; operational readiness and reliability, compliance with the requirements and needs of the community and achievement of minimum cost and maximum safety of firefighting participants. However, in the recent draft of the Strategy it is stated that it is "... necessary to create a proposal of a new organizational model of firefighting, whereby relations in the firefighting system at the town (municipality), county and state level would be precisely defined. As a matter of fact, over the past decade certain deficiencies or inaccuracies in the existing legislation have been observed ..." [20].

## OBSTACLES TO THE ACHIEVEMENT OF THE MISSION AND OBJECTIVES OF FIREFIGHTING IN CROATIA – THEORETICAL CONSIDERATIONS

Since 2000 the number of professional firefighters and professional units in Croatia has increased by about 20 % due to the introduction of new legislation ensuing from the adoption of the EU acquis, as well as the expansion of protection criteria. In spite of that, in circumstances of the economic crisis, local and regional governments are operating within the same or, in most cases, reduced budgets, which is inevitably also reflected in the funding of firefighting services. Another issue is the legislative struggle over a body that would be responsible for firefighting, with public authority. Although, according to the Law on Protection and Rescue, NPDR is a central government body in charge of the Fire Service, the Law of Firefighting defines all firefighting entities/units as belonging to CAF.

Therefore, the operational power of the Fire Service is based in a single entity (CAF), whereas the commanding function is also partly executed by that entity and partly by a state body (NPDR). Furthermore, the firefighting activity is under the jurisdiction of the state body also responsible for its management, while the local self-government is responsible for its financing. As a result, in firefighting practice certain patterns of inefficiency and insufficient cost-effectiveness and imprudence tend to emerge. This particularly applies to emergency situations related to fighting wildfire.

In the theory of modern organization the aforementioned problems are described as typical of large, horizontally differentiated structures and joint organizational action forms. In that respect, the identified problems are mainly associated with categories of interoperability and coordination, as well as the development of a consistent model of governance and decision-making. According to Lawrence and Lorsch [38], an appropriate organizational structure that regulates internal relations represents significant support for every organization in effectively responding to coordination and motivation issues. Although the emergence of information technologies has generally resulted in changes in the way of organizing over the last two decades, the selection of an adequate organizational structure remains an important issue. Different coordination mechanisms are used for coordination of individuals and organizational units in their effort to achieve common (organizational) goals. Coordination is also necessary in joint actions of several organizations [39]. Hartnett and Campbell [40] identify obstacles to coordination that often occur in the process of inter-organizational (-agency) and similar associations, including: organizational sovereignty, complex missions with great uncertainty, large differences between agencies in terms of force and resources; differences in programs, approaches and timelines between agencies; different cultures and communication systems; vertical bureaucratic barriers within agencies and coordinating policies. According to Chen et al. [41], effective coordination is an essential component of emergency response management. However, coordination of emergency response can be demanding because of high uncertainty and necessity for rapid decision-making and response on the one side and resource constraints on the other.

The question of interoperability has been gaining significance with the increasing number of organizations participating in joint operations, projects, missions and activities such as firefighting. According to the UK's National Policing Improvement Agency [42] interoperability in the context of multi-agency co-operation is the ability of an organization or individual parts of an organization to exchange operational information and use it for successful decision-making. Kubicek and Cimander [43] propose the following four levels of interoperability with related objects: technical (signals), syntax (data), semantic (information)

and organizational (processes). Interoperability between the command structure of firefighting and rescue includes the following [13]:

- compatible communications systems, equipment and control,
- joint agreements regarding command, control and coordination,
- effective information, notification and data sharing,
- compatible operating procedures and governance relying on familiar, common terminology, and
- compatible individual and collective training, and others.

According to Sutton [44], failure to achieve interoperability is the inability of the network to meet specified levels of interoperability, conditions and requirements, such as the minimum acceptable rate of data transfer, quality of service and the maximum allowable time of reaction. Firefighting performance is largely dependent on the average response time and response [45], for the improvement of which specific training strategies can be used [46]. Owing to their characteristics, some modern logistics systems can be classified as complex [47, 48]. Such systems are challenging to manage, because supporting mental or computational models that reduce complexity by omitting seemingly unimportant parts can lead to erroneous conclusions regarding the expected outcomes of the behavior of the organizational system.

The design of information systems for logistics, or for the purpose of fire protection, is of great importance. With the intent of better communication, coordination and resource management in crisis situations appropriate solutions are used, such as Critical Software PRIMFIRE [49], in addition to new ways of improving information-sharing and decision-making that are being considered [50, 51]. Below, after a theoretical interpretation of the fire service specificities, we shall focus on a more detailed description of the current situation, i.e. detection and formulation of problems in the Croatian firefighting system. For this purpose, we conducted a survey on the experience and attitudes of competent members of this service.

## **RESEARCH ON EMERGENCY RESPONSE IN THE FIREFIGHTING SYSTEM – WILDFIRE FIGHTING EFFICIENCY**

Emergency response for wildfire crises includes numerous factors which increase the complexity of such situations, including surprise, speed of development, spatial extension, number of involved stakeholders, uncertainty, lack of flexibility in decision-making, lack of available resources and reduced ability to communicate, among others [52]. Our research was designed and focused in a way to explore whether the indicated problems related to fighting wildfires concerning the accompanying logistics, organizational structure and legislation are recognized among the population of skilled firefighters. Generally speaking, research into the current state of an organization is one of the stages in the process of organizational redesign [53]. In other words, the aim of the research to obtain insiders' judgments regarding the organizational design issues that can be applied to subsequent systematic efforts in developing possible scenarios of emergency organization redesign.

## **SURVEY ON THE STATE OF FIREFIGHTING**

The sample of respondents in the survey was comprised of professional firefighters who had participated in fighting wildfire on several occasions as well as firefighting commanders. The sample can be characterized as a random sample drawn from the basic set of trained and experienced firefighters. It needs to be noted that they mostly belong to forces from the continental part of Croatia. The survey was conducted at the end of 2012. A total of 72 firefighters received the questionnaire by email or in courses and seminars, while it was

personally delivered to operational firefighters—members of the Intervention Firefighting Units of Croatia. From the administered questionnaires, 45 (62,5 %) were properly completed and returned. The questionnaire consisted of three sheets containing 11, 12 and 7 items, respectively. For the purpose of this study the first and the third sheet were used, with a total of 18 questions. The respondents' attitudes were tested using the 5-degree Likert scale. The questions are included in Table 3, in which the frequencies of individual responses are also shown. The items were formulated with regards to the research goals aimed at determining potential weaknesses in the operational functioning of firefighting and determining possible causes in the sphere of its internal and external organizational environment. Although it is evident that the sample of firefighters that participated in our study generally does not dispose of formal expertise regarding legislation, finances and logistics, it can be assumed that they base their own opinion about those issues on their own professional experience, and have formed attitudes or assumptions regarding the causes of inefficiency in the firefighting practice. Therefore, this observation is of particular importance in case of items 1, 7, 11, 15, 17 and 18.

## RESULTS

In accordance with the standards of research data processing, the required consistency of answers was first established in the data on respondents' attitudes collected by a questionnaire containing Likert-scale items. The Cronbach's alpha coefficient was 0,7915, which implies satisfactory reliability (see: Gliem and Gliem [54]).

In Table 3, the left-hand column contains the items and their numbering as well as information about inversely oriented items (marked INV, which denotes that a high degree of agreement with the statement indicates a negative attitude about the current state of the subject/topic in that item). The number of responses for each degree of agreement (*n*) is expressed in percentages. In subsequent quantitative analysis of responses, values of inverse items were reversed using the simple model (1 → 5, ..., 5 → 1). Next we divided the total set of items by four topics (Table 4). For three groups of items mostly negative attitudes of respondents were identified, with the average score slightly above the response 'mostly disagree' (score 2).

The basic sample of subjects in this study is comprised of competent and well-trained staff with experience in wildfire firefighting. It is assumed that there are approximately 3 000 (or slightly more) such members of the firefighting force in the firefighting system. That number is accounted for by the fact that every year 3 000 firefighters<sup>1</sup> (if all aggregated categories are considered) undergo necessary training, wherein instances of duplicated training and lack of experience with participating in firefighting are also included. A sample of 45 respondents is considered representative. By computing the mean estimate [55], and taking into consideration the aforementioned data, assuming that the standard deviation equals 0,6, we found that the mean of the basic set is determined by the arithmetic mean of the sample with the ± 0,17 interval range, with 95 % reliability. It is clear that the obtained (low) scores shown in Table 4 are not significantly shifted by this ambiguity.

**Table 3.** Responses to questionnaire items (continued on p.109).

<b>STATEMENTS</b>	<b>I entirely disagree</b>		<b>I mainly disagree</b>		<b>neutral or no opinion</b>		<b>I mainly agree</b>		<b>I entirely agree</b>	
	<b><i>n</i></b>	<b>%</b>	<b><i>n</i></b>	<b>%</b>	<b><i>n</i></b>	<b>%</b>	<b><i>n</i></b>	<b>%</b>	<b><i>n</i></b>	<b>%</b>
P1. Laws and regulations that govern firefighting facilitate optimum firefighting.	6	13.3	10	22.2	4	8.9	22	48.9	3	6.7
P2. The organizational firefighting structure fully enables an optimal course of action in fighting wildfires.	10	22.2	14	31.1	3	6.7	14	31.1	4	8.9

**Table 3.** Responses to questionnaire items (continuation from p.108).

P3. Participants in fighting wildfires are fully trained to perform these tasks.	5	11.1	15	33.3	0	0.0	20	44.4	5	11.1
P4. Alarmed forces for fighting wildfires regularly require additional logistical support. INV	1	2.2	3	6.7	0	0.0	15	33.3	26	57.8
P5. Supplying firefighting material and equipment at the fire site is timely and sufficient.	3	6.7	19	42.2	3	6.7	14	31.1	6	13.3
P6. In each major wildfire fighting action (regulated by existing laws) flaws in the logistics supply were manifested. INV	0	0.0	6	13.3	5	11.1	16	35.6	18	40.0
P7. Dislocated firefighting forces from other parts of Croatia completely fulfill the purpose of forces reinforcement.	9	20.0	10	22.2	2	4.4	14	31.1	10	22.2
P8. Logistical support to firefighters in the form of food and accommodation in extended firefighting actions is timely and sufficient.	7	15.6	26	57.8	4	8.9	8	17.8	0	0.0
P9. Basic and special occupational safety rules are fully observed in practice.	8	17.8	16	35.6	4	8.9	14	31.1	3	6.7
P10. Mutual communication between firefighting forces and 112 Center is optimal and ensures optimal forwarding of information.	7	15.6	22	48.9	8	17.8	6	13.3	2	4.4
P11. Local self-government units (city, municipality, companies) are regularly involved in actions of fighting wildfires.	3	6.7	27	60.0	4	8.9	8	17.8	3	6.7

## QUESTIONNAIRE: PART 2

P12. The basic prerequisite for effective wildfire fighting is to create a new legal framework. INV	1	2.2	2	4.4	6	13.3	21	46.7	15	33.3
P13. A key factor in enhancing the firefighters' capability (particularly that of operational forces) is permanent education of employees, especially commanders.	0	0.0	9	20.0	2	4.4	15	33.3	19	42.2
P14. For funding operational firefighting it is necessary to create a new model of funding firefighting at the state level. INV	0	0.0	0	0.0	6	13.3	11	24.4	28	62.2
P15. Compliance with tactical rules of wildfire fighting and occupational safety rules at work requires subordinate legislation in the form of new regulations governing firefighting. INV	0	0.0	2	4.4	4	8.9	24	53.3	15	33.3
P16. For force planning and resource allocation to be appropriately executed, new threat assessment and plans for fire protection are needed in addition to territorial vulnerability distribution. INV	0	0.0	3	6.7	4	8.9	13	28.9	25	55.6
P17. To consolidate all firefighting entities it is necessary to establish a central government firefighting body. INV	2	4.4	2	4.4	3	6.7	20	44.4	18	40.0
P18. In order to combat fire in coastal areas during fire season, it is necessary to employ a larger number of seasonal firefighters trained for wildfire fighting instead of dislocation from the continental part. INV	1	2.2	2	4.4	2	4.4	30	66.7	10	22.2
<b>SCORE</b>		<b>1</b>		<b>2</b>		<b>3</b>		<b>4</b>		<b>5</b>

**Table 4.** Items structured by topics.

Group of items	Attached questions	Mean ± St. dev.
Legal framework and firefighting funding model	P1, P12, P14, P15	2,13 ± 0,61
Organizational structure and governance	P2, P7, P10, P11, P16, P17, P18	2,34 ± 0,56
Competence and education of firefighters	P3, P9, P13	3,28 ± 1,00
Logistics support in firefighting actions	P4, P5, P6, P8	2,23 ± 0,59

Based on the data on the surveyed employees, we examined the relationship between the subjects' assessment and their characteristics with regards to: (a) their workplace and education level (linear combination labelled *position*), and (b) experience. The *Statistica* software package (version 12) was used for that purpose. We set the threshold for a medium correlation with the observed variables at  $r > 0,45$ . In Table 5, R. stands for 'respondent'. For the sample of respondents in our study, the values obtained for *R. position* are in the 1,00 – 3,67 interval, while those obtained for *R. experience* are within the 1,00 – 5,00 boundary interval. The correlation coefficients indicate that the respondents in commanding positions reported less favorable attitudes regarding organizational structure and logistics compared to other respondents.

On the other hand, respondents with more experience seem to have less favorable attitudes regarding the level of competence and education of the firefighting force for combating wildfire in Croatia as well as regarding the organizational structure. With the aim of further structuring of firefighting and emergency response issues, factor analysis was performed.

As shown in Table 6, four eigenvalues explain 70 % of the total variance. The main results of the factor analysis are presented in Table 7, which contains the obtained determining factors (1, 2, 3 and 4). The factors were extracted after performing varimax rotation, and are characterized by respective items as variables: Factor 1 (items P1, P2, P6, P8, P9), Factor 2 (items P12, P15, P16, P17), Factor 3 (items P14 and P18) and Factor 4 (items P4, P5, P7, P13). In accordance with the questionnaire items that determine the 4 factors (Tables 3 and 7), we can provide interpretation for each of the factors. Factor 1 refers to *existing legislation and flaws in the organization of firefighting*; Factor 2 is marked by *new legislation and new protection plans*; Factor 3 is determined by *a new financing model and new local engagement and seasonal employment*; in determining Factor 4 *firefighters' qualifications*

**Table 5.** Correlation matrix of respondents' attributes and their attitudes (scores).

Variables	Correlation values between variables					
	R. position	R. experience	Legal framework	Org. structure	Competence	Logistics
R. position	1,00	<b>0,46</b>	-0,22	<b>-0,51</b>	-0,44	<b>-0,50</b>
R. experience	<b>0,46</b>	1,00	-0,08	<b>-0,47</b>	<b>-0,54</b>	<b>-0,45</b>
Legal	-0,22	-0,08	1,00	<b>0,55</b>	0,18	<b>0,46</b>
Org. structure	<b>-0,51</b>	<b>-0,47</b>	<b>0,55</b>	1,00	<b>0,71</b>	<b>0,68</b>
Competence	-0,44	<b>-0,54</b>	0,18	<b>0,71</b>	1,00	<b>0,65</b>
Logistics	<b>-0,50</b>	<b>-0,45</b>	<b>0,46</b>	<b>0,68</b>	<b>0,65</b>	1,00

**Table 6.** Factor analysis – eigenvalues# 1 . #percentages of factor variance.

Component	Principal components and Eigenvalues			
	Eigenvalue	Variance, %	Cumulatively	Cumulatively, %
1	6,362909	35,34950	6,36291	35,34950
2	3,584541	19,91412	9,94745	55,26361
3	1,585348	8,80749	11,53280	64,07110
4	1,214363	6,74646	12,74716	70,81756

**Table 7.** Loadings of variables in factors. Factors bigger than 0,60 are marked.

Variable (question)	Factors ( <i>Varimax rotation</i> )			
	Factor 1	Factor 2	Factor 3	Factor 4
p1	<b>0,763551</b>	0,284733	-0,092096	-0,089775
p2	<b>0,630893</b>	-0,185926	0,251986	0,526852
p3	0,517702	-0,396947	-0,013465	0,547931
p4	0,157088	0,335245	-0,150275	<b>-0,681781</b>
p5	0,260762	0,235075	0,238493	<b>0,689134</b>
p6	<b>0,710259</b>	-0,384916	0,111539	0,233857
p7	0,219087	-0,145449	-0,054738	<b>0,847848</b>
p8	<b>0,629502</b>	-0,050683	0,270648	0,388248
p9	<b>0,605866</b>	0,272315	0,196920	0,328812
p10	0,198062	-0,028770	0,539009	0,555587
p11	0,572139	0,147597	0,589425	0,249279
p12	0,077669	<b>0,831207</b>	0,110836	0,026426
p13	0,398711	-0,227179	0,042411	<b>0,718874</b>
p14	0,279946	0,223110	<b>0,736861</b>	0,216152
p15	-0,083948	<b>0,797267</b>	0,074119	-0,162057
p16	0,302322	<b>0,843487</b>	-0,199568	-0,075012
p17	-0,235552	<b>0,710209</b>	-0,062042	-0,303766
p18	0,163874	0,445522	<b>-0,763567</b>	0,153777

and skills together with logistics and operational functioning ability are important. By using factor analysis a large number of variables (themes, features) was thus reduced to a small number of basic factors.

## CONCLUSIONS

In the organizational framework of the firefighting system it is assumed that the National Protection and Rescue Directorate is responsible for the planning, managing and coordination of the firefighting task force, while subjects such as the Croatian Firefighting Association and the local government are responsible for ensuring the readiness of forces (that is, for sending forces in emergency). Interoperability and coordination challenges, which undoubtedly exist, tend to lead to certain confusion in practice regarding, among others, the issues of control and command, as well as the responsibility for providing comprehensive logistical support. The situation in Croatia is by no means an exception when such challenges are concerned, as can be evidenced by other research into interorganizational communication in emergency situations on the European territory (e.g. see [7; p.1649]).

For the Republic of Croatia wildfires are an issue of utmost importance since their occurrence and extinction have been known to cause most severe and most frequent disorders in the functioning of society. In order to indicate a possible direction of organizational changes in the firefighting system, we conducted a survey on the attitudes and experiences of operational firefighting on a sample of 45 active firefighters from entire Croatia. This is a representative sample of the basic set of experienced and trained firefighters. Research into the attitudes of operational firefighters in this paper indicated certain overarching issues not limited to the effectiveness of wildfire fighting that call for the need to improve the emergency management system organization. However, conclusions arising from the evidence on the attitudes of the respondents participating in our survey should be drawn with caution and certain reservations, considering the indefinite nature of the respondents' knowledge of specific areas of concern: finances, logistics, organization as well as law.

The investigation of respondents' attitudes yielded results that can be summarized as follows:

- respondents are generally dissatisfied with the current situation and the degree of organization of logistical support infighting wildfires as well as with the organizational structure and the legal framework,
- respondents believe that a new model of (increasing) firefighting forces in the coastal area during summer months is desirable, as well as new plans for fire protection.

Firefighters with more experience and those with a higher rank and higher level of education were more stringent in their assessment of the organizational structure, logistics and legal framework for firefighting. Using factor analysis we showed that the identified characteristics and problems can be reduced to four topics/categories: existing legislation and flaws in the organization of firefighting, new laws and new protection plan, new funding model and local hiring; training and operation of the firefighting department.

Our future research may focus on the conceptual design of new legislation, processes and organizational structure that would allow better coordination, interoperability and greater efficiency. To successfully meet these goals, however, it is necessary to gain a deeper insight into the integrated emergency management system.

## REMARK

<sup>1</sup>According to National Plan for Engagement of Firefighting Forces and Participation in Firefighting, NPPD, 2013.

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## ORGANIZIRANJE ZA HITNE SITUACIJE – PROBLEMI U GAŠENJU VELIKIH POŽARA U HRVATSKOJ

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### SAŽETAK

Ulaskom Republike Hrvatske u članstvo Europske unije pokrenute su neizbjježne organizacijske promjene, te je i područje zaštite i spašavanja stanovništva zahvaćeno novim zahtjevima prilagodbe standardima i mjerilima Europske unije. Vatrogasnna djelatnost pri tome svakako ima vanjske i unutarnje poticaje svojim promjenama. S ciljem stvaranja suvremenog ustroja koji bi raspolagao potrebnom opremom i materijalnim resursima, učinkovit sustav vatrogastva Republike Hrvatske treba oblikovati i vodeći računa o zemljopisno- klimatskom području u kojemu je smještena naša zemlja. Skladno funkcioniranje većeg broja relativno autonomnih organizacija kod upravljanja u hitnim situacijama, zahtjeva jasne nadležnosti odlučivanja, dobro razrađene mehanizme koordinacije,

visoku interoperabilnost i potrebne kompetencije u ključnim područjima. U vatrogasnoj praksi utvrđene su određene manjkavosti pri gašenju velikih požara otvorenog prostora. U ovom radu dan je prikaz ustroja vatrogasnog sustava, prikaz prateće zakonske regulative, te razmatranje uočenih problema i pitanja u vezi funkcioniranja organizacije gašenja požara. Provedeno je anketno istraživanje kao ispitivanje stavova i iskustava pripadnika vatrogasne službe, a s naglaskom na uočene probleme u izvođenju operativnih aktivnosti. Kod skupine ispitanika utvrđena je prosudba relativno niske razine zadovoljavanja vatrogasne organizacije u vezi kategorija: organizacijska struktura, zakonska regulativa, logistička potpora kod gašenja požara. Vatrogasni djelatnici s višim obrazovanjem, oni na zapovjednim funkcijama i oni s više iskustva bili su kritičniji u ocjenjivanju postojećeg stanja. Rezultati istraživanja mogu poslužiti kao smjernice za redizajn organizacije vatrogastva kao i obuhvatnijeg sustava sigurnosti u RH.

## **KLJUČNE RIJEČI**

koordinacija i interoperabilnost, upravljanje hitnim situacijama, vatrogastvo, organizacijske promjene, anketno istraživanje

# QUALITY OF LESSONS IN TRADITIONAL AND ELECTRONIC TEXTBOOKS

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## ABSTRACT

The aim of this study is to verify and assess the quality of lessons in traditional and electronic textbook on general standards of textbooks quality. The method of theoretical analysis and content analysis was used. For the purpose of analyzing the contents of the sample we took teaching unit Measures and measurement from two textbooks: the traditional and the electronic. The electronic textbook, which has been the subject of research, is of quality and meets the standards of textbook quality.

## KEY WORDS

traditional textbook, electronic textbook

## CLASSIFICATION

JEL: I21, O14

PACS: 01.40.gb

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## INTRODUCTION

The textbook is one of the most important sources of knowledge. It contains the most important skills that students should acquire by the prescribed curriculum. Modern education has to include changes in the content of learning and teaching methods. E-learning is now very widely used in different activities of modernization of teaching because it is specifically in relation to other ways of learning (flexibility in the use of learning materials, choice of time for learning, personal responsibility for the dynamics and structure). The development of new technology causes the integration of technology into the teaching process. "Effective integration of technology into the teaching process requires teachers not only to use their knowledge about the use of technology in the learning process, but also to combine and integrate the technological and pedagogical knowledge" [1; p.49]. At the beginning of 2010 the company introduced the Apple iPad device, which marked the beginning of a major expansion of electronic devices called tablets (English: tablet, the Serbian is also called table). Tablets are characterized by a large touch-screens, light weight, relatively low cost, compactness and ease of use. Since the advent of the iPad, tablets experienced a great expansion in all areas of electronic communications, and deservedly occupy a leading role in the educational process. Today most states actively work on introduction of information and communication technology (ICT) in the teaching process, a special emphasis is given to the use of tablets in schools. In addition to the variety of platforms for distance learning, electronic materials (e-materials) and electronic books (e-books) are the basis of electronic education. Does this mean that the time has come to replace traditional teaching and books with electronic? The aim of the research comparing the quality standards of traditional and electronic textbooks is to check and evaluate the quality of lessons in traditional and electronic textbook on general standards of quality textbooks that are defined by Ivić, Pešikan and Antić [2]. The method of theoretical analysis and content analysis was used. The electronic textbook, which has been the subject of research, is of quality and meets the standards of textbook quality which are defined in [2].

## THEORETICAL APPROACH TO THE PROBLEM

This part of the work consists of several sub-chapters: Comparison of some issues in terminology, Theoretical consideration of the problem, Classifications of textbooks.

## COMPARISON OF SOME ISSUES IN TERMINOLOGY

The textbook is a teaching tool in which "the teaching material is given scientifically and accessible according to the curriculum of each subject" [3; p.1060]. The textbook is one of the most important sources of knowledge. It contains the most important skills that students should acquire by the prescribed curriculum. The lessons in it are logically systematized, that is distributed on the basis of cause-and-effect relationship. Lecture by teachers and text books complement each other.

The concept of textbook can be most completely defined as "each teaching tool or a combination of teaching aids) that contains systematized knowledge in some areas which are didactically configured for a certain level of education and a certain age of students, to have developmental and formative role and participate in the construction of students 'knowledge'" [2; p.24]. Regarding language, the textbooks should be written in a concise, easily accessible and picturesque language. The methodological side of textbooks must be systematically arranged, logically structured into chapters and sections, accompanied by pictorial texts and drawings, and so that the illustrated and textual materials there are organic

unity. Before defining the concept of an electronic textbook, it is necessary to define the concept of e-learning. To the question “What exactly is an e-learning?” D. Webster reported: “Quite simply, e-learning is simply learning that happens on your computer. At the present time, it usually means learning through the Internet, the information provided through the Internet search engine” [4; p.8]. High quality e-learning is, according to D. Webster, characterized by “a high level of interactivity, integration of simulation and animation, multimedia support, integration with classroom learning and the development of hybrid learning systems, being supported by various electronic materials in different formats, being founded on mutual learning of students and tutors, learning management system which is based on the possibilities of the web, etc.” [4; p.10].

Keller and Suzuki defined the concept of e-learning in a broad sense, so that it applies to almost any learning environment in which electronic media, such as computers, are used as a component of educational delivery systems [5; p.230].

E-learning is a revolutionary turning point in the education system. “The development and maintenance of effective e-learning can be even more challenging in the era of great technological progress” [6; p.253]. The fact is that the “modern web Technologies use communication, collaborative opportunities that are easily accessible and very popular among the younger generations, so that they can become a substitute to current methods of teaching and learning” [6; p.310]. And in some cases, e-learning can be more effective than of the traditional and confirm the following results: “E- learning of word studying proved to be more effective than traditional teaching. Based on the measurement of achievement of the participants it was concluded that there was no statistically significant difference between the two groups ( $t = -3672$ ,  $df = 36$ ,  $p = 0,001$ ) in favor of electronic teaching, which was confirmed by the test that was given two months later” [8; p.61].

The electronic textbook is not an electronic (scanned) form of traditional textbooks. “While there is no universally accepted definition of e-books, the electronic textbook implies a digital document that contains elements of classic books (text and images), and interactive elements such as audio/video recordings, various tests, simulations, and learning games and applets” [7; p.311]. Interactive elements at the rate of interactivity can be divided into three groups:

- elements with low interactivity – audio and video files, simple animations and simulations. These elements have only two controls – start and stop playback,
- elements with an average rate of interactivity – basic tests: yes / no tests, multiple choice tests and additions. Users of these elements have the ability to input answers, check the input and the ability to display correct answers, and
- elements with a high level of interactivity – advanced animations and simulations (in which the user can actively participate), advanced test (connecting, testing and correcting arrangement), applets and various learning games. In these elements, the user can dynamically change the look, content, input and output data as well as to get feedback depending on the activity.

It should be noted that “there is no ideal textbook, so that we should be constantly engaged, theoretically and practically, in creating better textbooks. This is achieved by a team work of creative professionals with different professions” [9; p.441].

## **THEORETICAL CONSIDERATION OF THE PROBLEM**

It is necessary that the textbook “with its content and didactic apparatus supports the construction (design) of knowledge of the learner” [2; p.24]. The tutorial is not only for the

transmission of knowledge, but the structure of knowledge, “a process of active construction of stable and usable knowledge, and to the student’s own effort, his thinking and actions” [2; p.25]. In addition to this important feature of quality textbooks, another feature is the content of the textbook adoption process, which is just as important as the content.

The content of textbooks should didactically be designed to ensure that the basic structure of knowledge is accepted by the person to whom this textbook is intended to establish communication with him. The textbook should be directed (focused, centered) on the students “to his developmental level of prior knowledge, motivation for learning, social and cultural background, value system” [2; p.26]. It is necessary that in the textbook there are illustrations – paintings, drawings, schemes, which are in necessary logical connection with textually processed curriculum. In Germany there is a system PROBITON (PRO program, BI images, TON tone), where using a computer in the electronic classroom combines text, still and moving images and sound.

Successful teaching with technology is a multidimensional process that “requires an understanding of the representation and formulation facilities of technology use, pedagogical techniques that use technologies in constructive ways to teach content; knowledge about what makes the content difficult or easy to learn and how technology can help; knowledge of students’ prior knowledge and theory, epistemology, and understanding how technology should be used to build on existing knowledge and to develop new” [10; p.98]. The students in the DEL (Distance e-Learners) classes achieved similar, and sometimes better results than traditional courses, confirming results 324 complete surveys in the Canadian province of New Faundland and Labrador. The problem is that students fail to complete their courses usually because of technical difficulties as a result of insufficient development of technical skills and lack of understanding of the issues “37,5 % of the students did DEL courses in high school completely, while the majority of students 62,5 % did not” [11; p.85].

The game stands out as a special activity that contributes to the development of children’s thinking. It entails a replacement of one concept to another, ie symbolic function. In the game, the child is head over himself; the game belongs, by Leo Vygotsky in the area of the next development. Available in the textbooks must be exposed in an interesting way, so that their adoption does not represent the student boredom, monotony, indifference.

The use of digital textbooks in elementary school classrooms helps students to concentrate during problem solving. “One reason digital textbooks may improve cognitive and thinking mechanisms is that their interactive nature makes them more interesting to the student. Our results support expectation that the use of digital textbooks will have positive effects on student learning by increasing student interest in the curriculum” [12; p.240].

The process of finding solutions in the electronic textbook that is the subject of our analysis is clearly shown in Figure 1. It shows didactic game which helps the student calculate the value of numerical expressions containing parentheses.

$$\begin{aligned}12 - (4 \cdot 0,5 + 1,6) &= 8,4 \\12 - (4 \cdot 0,5) + 1,6 &= 11,6\end{aligned}$$

**Figure 1.** The process of finding solutions.

## **CLASSIFICATIONS OF TEXTBOOKS**

In this section we present a way to classify traditional and electronic textbooks. It is important to point out that the textbook is the source of knowledge in which the teaching material is presented in a scientific, but also in intelligible way according to the curriculum.

### **Classifications of traditional textbooks**

Kobola classifies books as follows: comprehensive, differentiated, programmed. Comprehensive (synthetic, integral) textbook “encompasses the whole curriculum content for each subject and grade” [13; p.196]. It includes all components of the teaching process: preparing for a new topic, the lectures topics, practice, repetition and verification. Differentiated (branched, split) textbook on certain criteria (by subject, areas) divides learning contents into several separate small volumes, and includes a handout for students’ self-training. Programmed textbook brings teaching content very gradually (in small articles or steps), strongly activates the students in learning and provides feedback on the adequacy of the student’s activities. “So the highest level of didactic design is implemented in a programmed textbook” [13; p.196].

The same author mentions the emergence of multimedia textbooks, which not only serve to teach the complete knowledge, but by multimedia techniques (picture, word, movement, music) penetrate deeper into the consciousness: “Simultaneously excites many sensory areas, which guarantees a broader and deeper engagement of students, excites, strengthens and deepens the feelings and interests, mimicking the inductive logic of cognitive way, and thus more strongly activated by students and achieves integration of all his mental functions” [13; p.197]. And they are all foundations of successful teaching and learning.

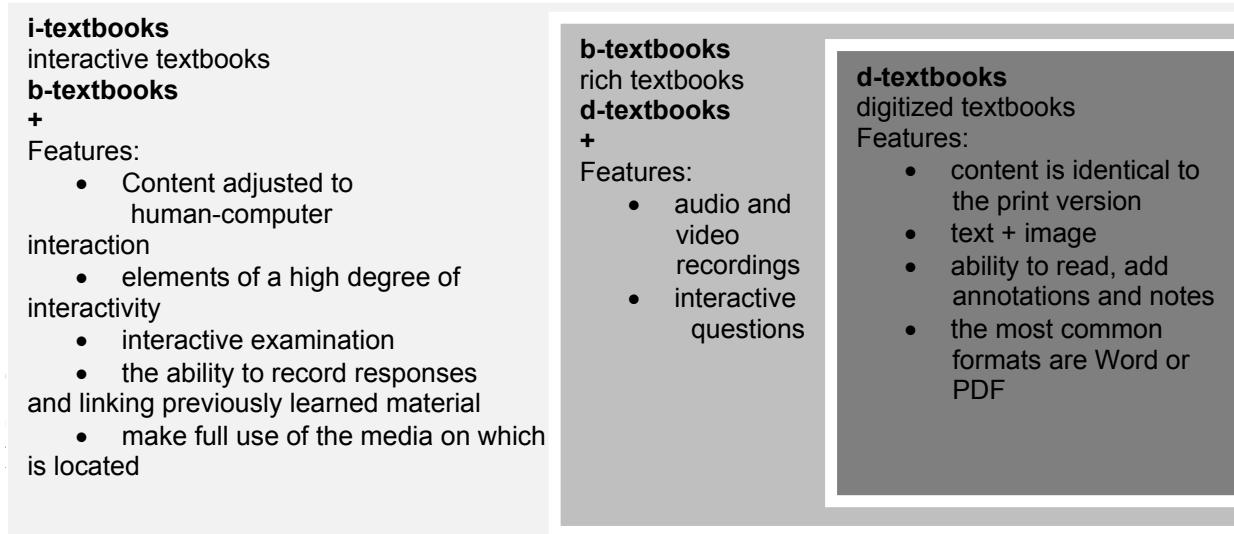
### **Classification of electronic textbooks**

Electronic textbook in the broad sense includes any electronic material that can be used as a teaching tool. Such materials differ in the degree of interactivity that is contained in them and it is necessary to make a more detailed classification of electronic textbooks.

The first electronic textbooks were electronic version of the classic (printed) book. They had the same elements as the classic textbooks – just text and images. These books have a practical advantage over the classical textbooks (mobility, distribution, search, edit mistakes ...) but there is no didactic advantage of these textbooks. Present-day electronic textbooks are much more than just an electronic image of classic textbooks. They contain lots of interactive material that cannot be integrated into the classical books – audio/video recordings, various interactive tests, quizzes and learning games.

Many electronic textbooks erroneously identified with an electronic version of the classic textbook, and therefore (UN) reasonable exercise challenge to their quality and the advantages over conventional textbooks. Therefore, it is necessary to carry out an accurate classification of the electronic books and correctly identify each of the types.

As noted above, the technical and didactic poorest electronic textbooks contain only text and images and such books are called digitized textbooks (**d-textbooks**). Content rich, interactive textbooks are called rich textbooks (**b-textbooks**) and they all except the D-textbooks contain additional audio recordings and interactive questions. Meaningful richest electronic textbooks are interactive textbooks (**i-textbooks**) that contain all the elements of b-books with elements of high rates of interactivity – learning games, dynamic structures, interactive examination of the possibility of recording responses, analysis of the performance and linking material. Technological advantages of interactive textbooks in relation to other is the complete suitability of content Human-Computer Interaction as well as platform independence of eContent



**Figure 2.** Classification of electronic textbooks.

which allows their presentation on all devices, from personal computers, to mobile computers and from tablets to smart phones.

## RESEARCH METHODOLOGY

The problem from which we started in this research is *whether the electronic textbook that is the subject of our analysis meets the standards of quality for textbooks?*

Subject of studies are the quality standards of traditional and electronic of textbooks based on certain standards of textbooks which were defined in [2].

The aim of this study is to compare the quality of lessons in traditional and electronic textbook on general standards of quality of textbooks that are defined by [2]. We selected the following standards:

V1. Lesson (thematic unit, a unit of study and exercise) as a functional unit.

V2. Coherence in the presentation of the content lessons (good logical organization of ideas).

V3. Clarity and uniformity of visual graphic design lessons.

Based on the extracted standards of quality of textbooks, we have defined the objectives of our research for both sample surveys: traditional and e-textbooks:

- 1) to estimate achievement of expected goals and outcomes using lessons (thematic units, units of learning and practicing) as a functional unit,
- 2) to estimate coherence in the presentation of the lessons content (good logical organization of ideas),
- 3) to estimate clarity and uniformity of visual graphic lessons design.

Based on this set of tasks, we proposed the following hypotheses:

H1. Achievement of expected goals and outcomes using lessons (thematic unit, a unit of study and exercise) as a functional whole is greater in electronic textbook.

H2. There is no difference in the assessment of coherence in the presentation of the lessons content (good logical organization of ideas).

H3. Clarity and uniformity of visual graphic lessons design, is greater in electronic textbook.

The method that we used in our study is the method of theoretical analysis and content analysis of textbooks. For the purpose of analyzing the contents of the sample we took the teaching of topics Measures and measurement of two textbooks: the traditional and electronic. Teaching lessons in a traditional textbook which is official textbook for

Mathematics for 4 grade, by Dusan Lipovac, can be found on page 21 and 22 [14; pp.21-22]. This electronic book is created in the framework of a bilateral project between the University of Maribor – Faculty of Sciences and University of East Sarajevo – Faculty of Philosophy called “Interactive learning of mathematics in the Republic of Srpska”.

## **RESEARCH RESULTS AND DISCUSSION**

Standards which are initial in our analysis are standards – V group; Quality lessons standards [2].

### **V1. LESSON (THEMATIC UNIT, A UNIT OF STUDY AND EXERCISE) AS A FUNCTIONAL UNIT**

Under the standard V1. the authors imply that “every lesson in the book has its totality and all its structural components that contribute to the achievement of the general objectives (outcomes, learning outcomes) and for which he entered into the program of the case” [2; p.64]. The lesson must have its purpose, that clearly shows the student what to learn and what achievement to accomplish. Structural components of the lesson, according to Ivan Ivic and Jelena Pesic, must contribute to the achievement of objectives (outcomes), and we separated them in Table 1. We made assessment of the achievement of expected goals and outcomes using lessons (thematic units, units of learning and practicing) as a functional unit on the basis of answers:

- 5 – totally agree with your statement,
- 4 – mostly agree,
- 3 – undecided,
- 2 – tend to disagree,
- 1 – strongly disagree with your assertion.

Based on the evaluations in Table 1 we concluded that the electronic textbook lesson has higher quality than the traditional textbook lessons on the following standards: Lesson allows assessment and self-assessment of progress in learning. Lesson in electronic textbook contains tasks that can be handled several times and can get quick feedback on performance. Quick feedback, and possible experience success motivate students, which is also one of the listed standards. Lesson in electronic textbook requires practicing skills, techniques and procedures more than a lesson in traditional textbook because besides mathematics knowledge, the knowledge of ICT is required, and the active participation of students is

**Table 1.** Structural components of the lesson.

<b>Structural components of the lesson Measures and Measurement</b>	<b>Lesson in traditional textbook</b>	<b>Lesson in electronic textbook</b>
Lesson transmits basic knowledge and skills.	5	5
Knowledge is adequately represented in the lesson.	4	5
Manner of explaining and designing the curriculum is systematic and functional.	3	5
The content of the lesson encourages student activities.	3	5
The lesson requires the practice of skills, techniques and procedures.	3	5
The lesson allows trying out thinking patterns.	3	3
Lesson stimulates and maintains the motivation to learn.	2	5
The lesson allows assessment and self-assessment of progress in learning.	2	5

needed which is one of the existing standards. The traditional textbook has only four tasks and combined lessons of measure, measurement, millimeters and kilometers on a single page. The electronic textbook has specific sites and specific tasks designed for each term, so that the way of explaining and designing the curriculum is systematic and functional. Hypothesis H1 Achievement of expected goals and outcomes using lessons (thematic units, units of learning and exercise) as a functional whole is greater in electronic textbook is confirmed.

## V2. TO ESTIMATE COHERENCE IN THE PRESENTATION OF THE LESSONS CONTENT (GOOD LOGICAL ORGANIZATION OF IDEAS)

This standard predicts that a lesson must have a clear and coherent structure exhibiting a given content, properly marked linguistic and graphical means.

Comparing lesson in traditional and electronic textbooks we conclude that the logical organization of ideas is better accomplished in electronic textbook, because the concepts and ideas clearly and logically follow and form the backbone, and on this basis we conclude that the hypothesis H2. There is no difference in the assessment of coherence in the presentation of the content lessons (good logical organization of ideas), has not been confirmed. All concepts of measure, measurement, millimeters, and kilometers are clearly separate, yet linked into a single unit (Figure 3). The course and development issues arising from such an organization is clear and logical, especially because the appropriate language and graphic resources are highlighted.

## V3. ESTIMATE CLARITY AND UNIFORMITY OF VISUAL GRAPHIC DESIGN LESSONS

The structure of the lessons should be spatial and visual-graphic labeled in a clear manner and consistently implemented throughout the entire book. Lesson in a traditional textbook is displayed in a simple manner. In contrast to this, the lesson of the electronic textbook is rich with images, animations, interactive questions and tasks with feedback, and didactic games



**Figure 3.** The coherence of content.

Шта мјерим?	Оцјена дужине	Мјерење	За колико сам погријешено-ла?
дужина врата	2 m 1 dm	2 m 8 cm	2 cm
ширина врата	9 dm	9 dm 3 cm	3 cm
...			

**Figure 4.** Clarity and uniformity of graphic design.

(Figure 4). We conclude that the clarity and uniformity of visual and graphic design of the lessons are greater in electronic textbook and thereby hypothesis H3 is confirmed.

The very appearance of site greatly affects the motivation to read and learn, “Structural wealth and good organization can contribute the preference to study from the textbook, since it break the monotony of text and highlights ideas from different angles” [2; p.70].

## CONCLUSIONS

Basic concepts associated with the notion of a textbook are discussed in the theoretical part of this paper, as well as the traditional textbook, electronic textbook, e-learning, content of textbooks, then the classification of traditional and electronic textbooks.

The electronic textbooks, which is the subject of our research has fully integrated all the proposed guidelines (scope and content of the measures and measurement issues, expected outcomes and guidelines for teachers) that are designed by the Curriculum<sup>1</sup> of the Republic of Srpska for school year 2013/2014.

In the second part of the research results of theoretical analysis of traditional and electronic textbooks are provided. Examining the quality standards of traditional and electronic books the following was determined:

- that the achievement of expected goals and outcomes using lessons (thematic unit, a unit of study and exercise) as a functional whole is greater in electronic textbook,
- that there is no difference in the assessment of coherence in the presentation of the lessons content (good logical organization of ideas),
- that the visibility and uniformity of visual graphic lessons design, is greater in electronic textbook.

The electronic textbook, which has been the subject of research, is of quality and meets the standards of textbook quality as defined in [2].

It is necessary to provide each student with the requirements of the educational process to experience success in learning, because success is a great motivating factor. Electronic textbook of mathematics, which is the subject of our analysis and assessment meets the basic prerequisites for success and fostering love for mathematics.

## REMARK

<sup>1</sup>available at [http://www.rpz-rs.org/sajt/doc/file/web\\_portal/05/5.2/Nastavni%20plan%20i%20program%20za%20osnovnu%20skolu.pdf](http://www.rpz-rs.org/sajt/doc/file/web_portal/05/5.2/Nastavni%20plan%20i%20program%20za%20osnovnu%20skolu.pdf), accessed 23<sup>rd</sup> November, 2014.

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## **KVALITETA SADRŽAJA TRADICIONALNOG I ELEKTRONIČKOG UDŽBENIKA**

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### **SAŽETAK**

Cilj ovog istraživanja je verifikacija i procjena kvalitete sadržaja tradicionalnog i elektroničkog udžbenika uobičajene razine kvalitete. Korištene su metode teorijske analize i analize sadržaja. Jedinica analize sadržaja bila je nastavna jedinica "Mjerne veličine i mjerjenje" iz dva udžbenika: tradicionalnog i elektroničkog. Razmatrani elektronički udžbenik jednake je kvalitete kao i tradicionalni udžbenik.

### **KLJUČNE RIJEČI**

tradicionalni udžbenik, elektronički udžbenik

# ASSESSING CREDIT DEFAULT USING LOGISTIC REGRESSION AND MULTIPLE DISCRIMINANT ANALYSIS: EMPIRICAL EVIDENCE FROM BOSNIA AND HERZEGOVINA

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## ABSTRACT

This article has an aim to assess credit default prediction on the banking market in Bosnia and Herzegovina nationwide as well as on its constitutional entities (Federation of Bosnia and Herzegovina and Republika Srpska). Ability to classify companies into different predefined groups or finding an appropriate tool which would replace human assessment in classifying companies into good and bad buckets has been one of the main interests on risk management researchers for a long time. We investigated the possibility and accuracy of default prediction using traditional statistical methods logistic regression (logit) and multiple discriminant analysis (MDA) and compared their predictive abilities. The results show that the created models have high predictive ability. For logit models, some variables are more influential on the default prediction than the others. Return on assets (ROA) is statistically significant in all four periods prior to default, having very high regression coefficients, or high impact on the model's ability to predict default. Similar results are obtained for MDA models. It is also found that predictive ability differs between logistic regression and multiple discriminant analysis.

## KEY WORDS

Bosnia and Herzegovina, default prediction, logistic regression, multiple discriminant analysis, banking

## CLASSIFICATION

JEL: G17, G33, G53

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## **INTRODUCTION**

Ability to classify companies into different predefined groups is an important business research issue [1], which can be utilized as a strong risk management tool. Default prediction has been an important area of business interest for many researchers, from the theoretical and practical aspect [1-29], as it is an integral part of the credit risk, which is considered to be one of the most important banking risks [2]. Expert default prediction interests a wide range of stockholders such as banks, microcredit organizations, insurance companies, other creditors, auditors and more. The increase of default occurrence can be linked to the latest global financial crisis and appropriate credit risk management.

Many economists consider the latest global financial crisis to be the worst crisis since the Great Depression. Many European countries like Greece, Portugal, Italy and Ireland are facing severe financial and liquidity crisis, which are likely to lead to further issues such as mass demonstrations, European currency crisis, further jobs reduction. Financial crisis is defined in the relevant literature as a “disturbance to financial markets that disrupts the markets capacity to allocate capital – financial intermediation and hence investment come to a halt” [30]. It is believed that one of the main causes of the crisis lies in the collapse of large financial institutions, generally banks around the world.

International Convergence of capital measurement and capital standards segments three main parts of the minimal capital requirements for banks. The main three parts used for calculation of minimal capital requirements are credit, operational and market risks [31].

Assessing the probability of occurrence of credit default is the main interest of this research. According to the definition given by Basel Committee on Banking Supervision [31] credit default occurs when one or more of the following takes place:

- “It is determined that the obligor is unlikely to pay its debt obligations (principal, interest, or fees) in full;
- A credit loss event associated with any obligation of the obligor, such as charge-off, specific provision, or distressed restructuring involving the forgiveness or postponement of principal, interest, or fees;
- The obligor is past due more than 90 days on any credit obligation or
- The obligor has filed for bankruptcy or similar protection from creditors.”

In predicting credit default existing literature uses several classification techniques such as multiple discriminant analysis, linear probability, logit analysis, probit analysis, multinomial logit, decision trees, and artificial neural networks.

The main purpose of this study is to assess the probability of default occurrence on the banking market from Bosnia and Herzegovina. In other words the main purpose of the study is predict credit default, or to create a prediction model that distinguishes defaulted and non-defaulted companies, based on the financial data obtained from their financial statements. Since no such research with data including both Bosnia and Herzegovina entities, has been performed, the purpose of this study to construct the first credit default prediction model on the country, as well as on the entities levels, using traditional statistical such as logistic regression (logit) and multiple discriminant analysis (MDA). Since Bosnia and Herzegovina is constructed of two separate entities (Federation of Bosnia and Herzegovina and Republic of Srpska) the purpose of the research is focused on the entities as separate banking markets and on the country level as a whole. The only similar published study in the past constructed a default prediction model using data one-year prior to default and was focused on data from Federation of Bosnia and Herzegovina [3].

Additionally, the data used in this study includes financial figures for a large sample of companies, up to four years prior to default, enabling creation of several default prediction models one, two, three and four years prior to default. Comparison of predictive ability between different techniques is assessed on the basis of time to default, in order to define which technique has the best default predictive ability, when applied to the banking dataset from Bosnia and Herzegovina. Corporate financial data in different research fields is also used for other purposes such as tax evasion detection [32], which have an aim at optimizing the business processes, improve financial stability and public revenues.

The results of this research should have a practical application in an everyday risk assessment performed by creditors, especially banks operating on the market whole of Bosnia and Herzegovina as well as in the banks registered in only one of the Bosnia and Herzegovina entities, since it will be the first default prediction model. The results of the research are expected to contribute to better risk management, of existing risk as well as in the process of assessing the risk of new potential clients in financial institutions. The costs of wrong credit risk assessment in financial institutions, especially banks, can be enormous. Approving loans to companies with high risk (represented through probability of default) consecutively lead to high loan loss provisions.

Creating an effective default prediction model using an original data from Bosnia and Herzegovina banking market will help different stakeholders manage risks more efficiently. Banking market of Bosnia and Herzegovina is divided into two parts. Each entity is regarded as a separate banking market having its own regulating authority. Some large foreign banking groups have two separate banks in Bosnia and Herzegovina, one in Federation and one in Republic of Srpska.

The main question behind the study is determining a way to detect of discriminate bad from good credit applicants, without having to make long, detailed and thorough human-based financial analysis. It is usually a case, that credit officers are engaged and responsible for conducting such financial analysis, using different combinations of financial ratios. The calculated financial ratios are than compared to historically define optimal ranges, as comments are given to each one of them. The main issue emerging in conducting such an analysis appears in the form of constructing an overall assessment whether the analyzed company is creditworthy or not. In other words it is a very difficult task to assess whether an analyzed company is healthy or has a potential to default in the coming period. If no other data is available, it is also not an easy task to differ already defaulted and financially healthy companies.

The main research questions, aimed at solving such a problem are defined as follows:

- 1) Is it possible to predict credit default in Bosnia and Herzegovina using traditional logistic regression?
- 2) Is it possible to predict credit default in Bosnia and Herzegovina using multiple discriminant analysis?
- 3) Is credit default prediction identical for all groups of companies in Bosnia and Herzegovina, with regards to their size and geographical location?

Once the research questions are answered, it should be possible to discriminate between defaulted and healthy companies, on the basis of information included in companies' financial statements. The research questions include two different groups of model creation methods, giving the study a multidimensional approach to credit default prediction issue.

The organization of the paper is as follows. Section 2 presents the reviewed literature on the default prediction. Section 3 presents the used methodology while Section 4 shows the data used and results obtained. Section 5 summarizes the paper with the concluding remarks.

## LITERATURE REVIEW

Unlike in many modern European countries, banking market in Bosnia and Herzegovina has very complex legal and inefficient and ineffective structure. Even though the banking market in Bosnia and Herzegovina is considered as one of the most developed, its complex and inefficient structure leaves a large space for further improvements. Undeveloped structure of the financial market in Bosnia and Herzegovina leaves the banking sector as the main source of financing the economy.

The Constitution of Bosnia and Herzegovina defines that the country structure consists of two separate entities: Federation of Bosnia and Herzegovina and Republic of Srpska and one district. Likewise, each entity has its own banking market. Another difference between Bosnian banking market and other developed European markets is in the regulator authority. Central Bank of Bosnia and Herzegovina is the authority in charge of the monetary policy, however the authority of regulating the banking sector is granted to each entity. Each entity has its own law on banks as well as its own banking agency (Banking Agency of Federation of Bosnia and Herzegovina and Banking Agency of Republic of Srpska).

Credit risk is defined as “the degree of value fluctuations in debt instruments due to changes in the underlying credit quality of borrowers and counterparties” [4]. According to one study [5] three main variables affecting the credit risk of a financial asset are Probability of default (PD), Loss-given-default (LGD) and Exposure at default (EAD).

Many risk management models have been constructed previously, such as Algorithmics, CreditMetrics, CreditRisk+, KMV’s Portfolio Manager, Loan Pricing Corporation, McKinsey’s Credit Portfolio View and others. Most of them were constructed by large global banks such as J.P. Morgan and Credit Suisse [6].

Another study [7] divided all bankruptcy prediction models are divided into three main groups: statistical model group (MDA, logit), artificial intelligence models (RP and ANN) and theoretical models (entropy theory).

One of the earliest studies [8] reports that the ratio analysis was born with the construction of current ratio as the first indicator of credit worthiness. It has developed ever since, as it includes multiple different ratios. It is used very often for decision-making processes by lenders, rating agencies, investors, regulators, management and others. The study uses data from financial statements that are created according to internationally accepted reporting standards. The final sample chosen from the Moody’s Industrial Manual database included 79 failed companies from the period 1954-1964. These 79 companies belonged to 38 different industries. Non-failed companies were added to the sample matching the industry and size of failed ones. Five years before failure financial statements were collected. Six different groups of financial ratios were calculated including cash flow ratios, net-income ratio, debt to total asset ratios, liquid asset to total asset ratios, liquid asset to current debt ratios and turnover ratios. Mean values of each ratio were compared between failed and non-failed companies.

Altman [9] created the fundaments of all bankruptcy prediction models. The purpose of his study was to assess the quality of ratio analysis. The sample used in the study included corporate manufacturing companies and it was divided into two main groups. The first group included 33 corporate manufacturers that filed a bankruptcy petition under Chapter X of the National Bankruptcy Act in the period of 1946-1965, while the other group included the same number of non-bankrupt companies. The average size of the sample companies was \$ 6,4 million. Set of financial ratios proposed in the literature was used in the study to as potential predictors of bankruptcy. Financial data up to five years prior to bankruptcy were taken into

consideration. Used financial ratios were divided into five standardized groups: liquidity, profitability, leverage, solvency and activity.

Altman [10] revised two models for assessing the distress of industrial corporations. The models assessed are called Z-Score model and ZETA® credit risk models. These models study the unique characteristics of business failures by assessing the influential financial variables that can predict the occurrence of default. Ratio analysis of financial variables is the fundament in this study. This study is an extension to Altman's previous studies, as it includes companies that are not traded publicly, non-manufacturing companies. The model also includes a new bond-rating equivalent model for emerging markets corporate bonds. The list of 22 variables (ratios) was used in the final analysis and they represented five groups of financial ratios: liquidity, profitability, leverage, solvency, and activity. Finally five ratios were used out of the starting 22 since they showed the best bankruptcy prediction ability.

The main purpose of another study was to construct a bankruptcy model, which would classify companies up to five years prior to failure of bankruptcy [11]. Used data set covered the period between 1969 and 1975. Linear and quadratic analysis was used in the study. The variables used in the study were return on assets, stability of earnings, debt service, cumulative profitability, liquidity, capitalization and size. Their results show that 7-variable ZETA bankruptcy model successfully predicts 90 % of the sample one year prior to bankruptcy and about 70 % of the sample five years prior to bankruptcy. The used sample in the study consisted of 53 bankrupt companies and 58 non-bankrupt ones. Linear and quadratic methods were used as the linear model showed 96,2 % for the bankrupt and 89,7 % accuracy for the non-bankrupt companies. The total linear model accuracy was 92,8 %. Quadratic model showed 94,3 % for the bankrupt, 91,4 % accuracy for the non-bankrupt companies and total accuracy of 92,8 %.

The first and only study on default prediction using financial data from Bosnia and Herzegovina used data from one of the entities in Bosnia and Herzegovina to create the first default prediction model in Bosnia and Herzegovina [3]. The study included 599 companies registered in Federation of Bosnia and Herzegovina and were divided into an original and holdout sample. Each company in the sample was assigned 15 financial ratios from the following ratio groups: profitability, liquidity, activity, leverage and coverage. Six variables that were extracted from the PCA were used in the logit analysis, which produced the default prediction model. The total classification accuracy of the model was 81,3 % with 95,6 % of correct classification of non-defaulted companies and 36,1 % of defaulted companies.

Deakin [12] analyzed possibility of business failure prediction by using multiple discriminant analysis, which finds a linear combination of ratios that discriminated between the desired groups, which should be classified. The author's goal was to replicate previous studies conducted by [8, 9] using the same financial ratios. The sample consisted of 32 failed companies that experienced failure between 1964 and 1970, where by failure any form of bankruptcy, insolvency or liquidation was included. The failed companies were matched with non-failed ones on the basis of industry classification, year and the asset size. Financial data (financial ratios) for sampled companies were collected for the period of up to five years prior to bankruptcy. The author found that the relative importance of the variables changes over the five years prior to bankruptcy and that almost all of the variables contribute significantly to the discriminant ability of the function. The results showed that the prediction ability in the first three years was larger than in the fourth and fifth year prior to failure. The author concludes that the statistical technique of discriminant analysis can be used accurately for failure or bankruptcy prediction up to three years in advance. Although the study brings an interesting and a significant contribution to the bankruptcy prediction theory, it must be stressed out that the sample used in the study is relatively small.

Lau [13] presented a model that differs from the previous models in a way that instead of the failing and non-failing dichotomy it represents a five financial states that approximate the financial state of a company, and instead of classifying the firm into one of two financial states, this study provides a probability that a company will enter each of the five predefined financial states. The five presented financial states are: financial stability state, omitting or reducing dividend payments state, technical default and default on loan payments state, protection under X or XI of Bankruptcy Act and bankruptcy and liquidation. The results showed that each of the used explanatory variables assumed different values for companies in different predefined states. The paired t-tests showed that for each variable the five state means are significantly different. In order to construct the model multinominal logit analysis (MLA) was used. The authors also used multiple discriminant analysis (MDA) to compare the study results. The results showed that MLA outperformed MDA. The author reported overall 96 % prediction accuracy for the model that used one year before default data, 92 % prediction accuracy for the model that used two years before default data and 90 % prediction accuracy for the model that used three years before default data.

One study utilizes three different methods for bankruptcy prediction and classification: discriminant analysis, logistic regression analysis and genetic algorithms, whereas each of them has a different set of assumptions. Data consisted of financial statements of 74 Finish companies three years before default, equally divided between defaulted and non-defaulted. Failures used in the study occurred between 1986 and 1989. Total of 31 financial ratios were classified into three main groups of liquidity, solidity and profitability. Factor analysis with Varimax rotation was conducted to whether variables in different models are describing different financial dimensions. For the data one year before bankruptcy neural networks had the lowest Type I (5,26 %), Type II (0,00 %) and total error (2,70 %) between the three methods. Discriminant analysis had the lowest Type I (24,32 %), Type II (18,92 %) and total error (21,62 %) between the three methods for the data two years before bankruptcy. Three years before bankruptcy neural network had the best predictive ability or the lowest error rates as well [14].

Ohlson [15] studied bankruptcy prediction using the logit model and it was chosen instead of MDA to overcome the problems associated with MDA such as statistical requirements imposed on the distributional properties of the predictor variables. The data used in the study are from the period between 1970 and 1976 from the Compustat database, and the sample excluded small or privately held corporations, utilities, transportation companies, and financial services companies. Financial data for the failed companies were collected for the period of three years before bankruptcy. The final sample included 105 failed companies. Total number of 2058 healthy companies was added to the sample. Three different models including an intercept and the nine independent variables were made, see Appendix A. Their predictive abilities were 96,12 %, 95,55 % and 92,84 %.

Another study used a sample of Croatian companies to classify them into distressed of non-distressed group, based on 15 financial ratios [16]. The methods of logit analysis, MDA and multidimensional scale (MDS) were used. Financial statements of Croatian companies from 2002 were obtained. Seven different industries were represented in the sample. Unlike many of the previous bankruptcy prediction studies, the companies in the sample were classified into three different groups: good, bad and medium, representing different levels of credit risk. MDA results showed that three variables were statistically significant as they represented liquidity and profitability ratios. MDA model correctly classified all good companies, while the classification of bad companies was very low with a hit ratio of 57 %. The overall predictive accuracy of the MDA model on the Croatian data set was 89 %. MDS model correctly classified 97 % companies (100 % of good and 88 % of the bad companies) and it

included six financial ratios. Logit analysis included three variables in the study and had an overall predictive ability of 93 % (95 % of good and 88 % of the bad companies). These results showed that MDA had the best predictive ability among the used techniques.

Šarlija [17] used logistic regression, decision trees and neural networks to predict bankruptcy on a sample of 200 loan applications. Out of the 200 applications 67 were defaulted afterwards, while the remaining 133 were good loan decisions. The data was obtained from one Croatian credit-deposit institution. Seven groups of predictor characteristics were used (business idea, growth plan, marketing plan, entrepreneur characteristics, business characteristics, credit program characteristics, lending institution-entrepreneur relationship). The best predictor of credit default on this study was logistic regression with 83 % of correct classification. Different models of ANNs (from 44 % to 69 %) and DTs (from 44 % to 79 %) had lower predictive ability.

Croatian sample was also used in the study that aimed at predicting short term illiquidity. The results of the study have shown that financial ratios from all five groups are statistically significant in short term liquidity prediction. The study utilized additional variables indicating the company's geographical location and industry type, which show that liquidity differs among companies located in different geographical locations as well as for companies from different industries [7].

## METHODOLOGY

Based on the previous default prediction research, list of most frequently used financial ratios was assessed, and calculated for each defaulted and healthy company in the sample. The data patterns were analyzed for the total data set and for each of the groups of companies separately (defaulted and healthy group).

Two main groups of methods were used to test the posed hypothesis and answer the research questions. The collected data was analyzed by a group of traditional statistical methods represented by logistic regression and multiple discriminant analysis. The outcome of the study is a set of default prediction models created using two different techniques:

- on a country level,
- on constitutional entities level,
- for SMEs,
- for large corporate companies.

Hypothesis testing has been performed after the prediction models were created. The predictive ability of created prediction models using logistic regression and MDA (see Appendix B) was compared in order to detect optimal combination of the applied technique and used subset of data.

The research aims at creation of the first default prediction models in Bosnia and Herzegovina. The first and only prediction model for Federation of Bosnia and Herzegovina was created [3] as one-year, prediction model created using data from one of the two entities in Bosnia and Herzegovina, using a single statistical technique. This research aims at creating a multi-period prediction models with a utilization of a wider set of statistical and artificial intelligence methods.

Logistic regression analysis is a statistical technique often used for in different fields of research such as medical and social sciences, marketing, movie industry, finance and many more. It was introduced in late 1960s as an alternative to ordinary least squares (OLS) regression. It found a wide application in statistical software programs during 1980s [33].

Its main goal is to find the best fitting model that best describes the relationship between an outcome and the set of independent variables [34, 35]. The main mathematical concept under the logistic regression is the logit or the natural logarithm of an odds ratio.

Logistic regression as a statistical method is suited and usually used for testing hypothesis about relationships between a categorical dependent or an outcome variable and one or more categorical or continuous predictor or independent variables. The dependent variable in logistic regression is binary or dichotomous. The maximum likelihood method, which yields values for the unknown parameters, is used for estimating the least squares function. Logistic regression solves such problems applying the logit transformation. Logistic regression predicts the logit of Y to X. Since the logit is the natural logarithm (ln) of odds of Y, and the odds are the ratios of probabilities ( $\pi$ ) of Y happening to probabilities ( $1 - \pi$ ) of Y not happening. The dependent variable in logistic regression can be presented as follows:

$$Y = \begin{cases} 1 \\ 0 \end{cases}. \quad (1)$$

Let us denote the  $p$  independent variables by the vector  $X' = (x_1, x_2, \dots, x_p)$ . If the conditional probability of the outcome is  $\pi(Y = 2|x)$ , the logistic regression model is given by the following equation

$$\pi(x) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p. \quad (2)$$

The logistic regression has the following form

$$\text{Logit}(Y) = \text{natural\_log}(odds) = \ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta x, \quad (3)$$

$$\pi = \text{probability}(Y = \text{outcome of interest} \mid X = x, \text{ a specific value of } X) = \frac{e^{\alpha+\beta x}}{1+e^{\alpha+\beta x}}, \quad (4)$$

where  $\pi$  is probability of the outcome of interest,  $\alpha$  intercept of  $Y$  and  $\beta$  regression coefficient. The logistic regression can also be stated in the form of odds:

$$\frac{\pi_i}{1-\pi_i} = \exp(\alpha + \beta_1 X_i), \quad (5)$$

It can also be presented in terms of probability:

$$\pi_i = \frac{\exp(\alpha + \beta_1 X_i)}{1 + \exp(\alpha + \beta_1 X_i)}, \quad (6)$$

In logistic regression the value of the coefficient  $\beta$  determines the direction of the relationship between  $X$  and the logit of  $Y$ , while  $\alpha$  and  $\beta$  are usually determined by maximum likelihood method (ML). The data are entered into the analysis as 0 and 1 coding for the dichotomous outcome. Usually, the null hypothesis of the logit model states that all  $\beta$ -s are equal to zero. If there exists at least one  $\beta$  different from zero the null hypothesis is rejected, and the logistic regression model predicts the probability of an outcome better than only the mean of the dependent variable marked as  $Y$  [36]. The probability of  $X$  or  $\pi(X)$  does not have a linear relation to coefficients in the logistic function, and the maximum likelihood is used. The maximization of the likelihood function expresses the probability of the data set as a function of the unknown parameters:

$$L(b) = \prod_{i=1}^n \pi_i(x_i)^{y_i} [1 - \pi_i(x_i)]^{1-y_i}. \quad (7)$$

The use of logistic regression requires certain data pre-processing and model building methodology. In data pre-processing phase a question of variable selection is raised. The dependent variable is dichotomous representing a state of distress or no distress, while the dependent variables can be dichotomous or continuous usually representing financial ratios. Logistic regression is less sensitive to statistical assumptions than the other statistical techniques. Missing values are also an important topic in the use of logistic regression in

bankruptcy forecasting, since financial statements differ between companies from different industries. Missing value problem can be solved either by deleting cases with any missing value, by filling the gap with the mean value of other cases or by computing the missing variable value from a regression equation estimated against the other variables. Many different model-building methodologies exist in logistic regression such as stepwise procedure (forward and backward development). Wald statistic with the 10 % significance level is probably used for variable removal. The model classification power for the logistic regression is computed by the chi-square statistic [18, 36].

Discriminant analysis is a statistical technique used in many different fields and it includes a discriminant variety and represents a linear combination of two or more independent variables that discriminate between the objects in the a priori defined groups [37]. Discriminant analysis is mainly used for solving classification and prediction problems [19]. Similar to the logistic regression the dependent variable is dichotomous. The discriminant function has the following form:

$$Z_{jk} = \alpha + w_1 x_{1k} + w_2 x_{2k} + \dots + w_n x_{nk}, \quad (8)$$

where  $Z_{jk}$  is discriminant  $Z$  score of the discriminant function,  $\alpha$  the intercept,  $w_i$  the discriminant weight for independent variable  $i$ , while  $x_{ik}$  is the independent variable  $i$  for object  $k$ .

The probability that a case with a discriminant score of  $Z$  belongs to group  $i$  is estimated by the following equation:

$$\pi(G_i|D) = \frac{\pi(D|G_i)\pi(G_i)}{\sum_{j=1}^n \pi(D|G_j)\pi(G_j)}, \quad (9)$$

where the prior represented by  $\pi(G_i)$  is an estimate of the likelihood that a case belongs to a certain group [1]. The objects are classified into one or the other group on the basis of the obtained  $Z$  score, whether it is higher or lower than the predefined cut off value. Multiple discriminant analysis computes the discriminant coefficients. The main advantage of MDA is in the ability to classify objects, by analyzing the total variable profile of one object simultaneously [9]. The discriminant analysis creates a vector of weights in a way that the sum of the products of the each element of the vector times the corresponding ratio produces a score that maximizes the distinction between the predefined groups. The distance between the centroids of the two groups is used to test the statistical significance of the discriminant model. If the overlap is small enough the two groups can be considered as different, and vice versa [12].

Multiple discriminant analysis assumes several statistical assumptions such as: normal distribution, homogeneity of variances/covariance, correlations between means and variances, multicollinearity.

Since the main aim of the study is to predict occurrence of default, the dependent variable shows the existence or non-existence of the state of default. Banking data including indicators of default was used for determining the dependent variable. Companies being in delay of bank debt service more than 90 days, according to Basel II principles [31], are regarded as defaulted or distressed. There are several reasons why state of default, as a separation limit was chosen instead of state of bankruptcy in this research:

- defaulted companies are the ones being in delay of debt servicing for more than 90 days. Bankruptcy in practice usually occurs long time after the state of default took place. Bankrupt companies can be in default for several years before the bankruptcy announcement. This is the main reason why default was used as a trigger instead of bankruptcy,

- banks are obliged to internally exclude booking of regular interest income for clients once they are defaulted,
- defaulted assets are regarded as non-performing assets.

## DATA AND RESULTS

Once all of the companies being in the state of default are extracted, only the ones transferred from healthy to defaulted, during the year of 2011 were retained in the sample. For each of the company that defaulted during the year of 2011, financial data was collected. The financial data for this study will be obtained from AFIP<sup>1</sup> database for Federation of Bosnia and Herzegovina and from APIF<sup>2</sup> database for Republic of Srpska data. These databases consist of financial statements of all of the companies registered in Federation of Bosnia and Herzegovina and Republic of Srpska. The total number of legal entities registered in AFIP database of Federation of Bosnia and Herzegovina in the year of 2010 exceeds 20 000 while in APIF database of Republic of Srpska the number of legal entities exceeds 9 000. Companies with inconsistent and incomplete financial statements were left out. For all of the sampled defaulted companies from both entities, financial statements for up to four years before default were collected. Healthy companies from both entities were added to the sample. Financial statements for the healthy companies were collected for at up to four consecutive years. The years of financial statements are matched for defaulted and healthy companies.

Sampling procedure began with choosing defaulted companies. Available bank data bases were used to detect defaulted companies (Basel II default methodology). To ensure proper dispersion, several banks' default data bases were combined. Based on the total created default dataset, which included companies from Federation of Bosnia and Herzegovina, Republic of Srpska, large corporate companies and SMEs, sample was chosen using random method. Based on the number of randomly chosen defaulted companies, healthy companies were added, also using random sampling method. The ratio between defaulted and non-defaulted companies was created to ensure proper representation of default-healthy ratio expected on the market in the coming periods. The default-healthy ratio used was assessed based on historical data and trends, which are clearly indicating further deterioration on loan portfolios of banks operating in Bosnia and Herzegovina. Larger share of defaults was intentionally included in the final sample, since Type II errors, represented by misclassification of defaults as healthy companies, are several times more costly than Type I errors.

**Table 1.** Data structure on country level (D – defaulted, H – healthy). Source: author's calculations.

	<i>t – 4</i>			<i>t – 3</i>			<i>t – 2</i>			<i>t – 1</i>		
	D	H	Total									
FB&H	272	279	<b>755</b>	292	484	<b>776</b>	292	484	<b>776</b>	292	484	<b>776</b>
RS	113	280	<b>393</b>									
<b>B&amp;H</b>	<b>385</b>	<b>763</b>	<b>1,148</b>	<b>405</b>	<b>764</b>	<b>1,169</b>	<b>405</b>	<b>764</b>	<b>1,169</b>	<b>405</b>	<b>764</b>	<b>1,169</b>

**Table 2.** Data structure on company size level (D – defaulted, H – healthy). Source: author's calculations.

	<i>t – 4</i>			<i>t – 3</i>			<i>t – 2</i>			<i>t – 1</i>		
	D	H	Total									
COR	194	279	<b>473</b>	198	279	<b>477</b>	198	279	<b>477</b>	198	279	<b>477</b>
SME	191	484	<b>675</b>	207	485	<b>692</b>	207	485	<b>692</b>	207	485	<b>692</b>
<b>B&amp;H</b>	<b>385</b>	<b>763</b>	<b>1,148</b>	<b>405</b>	<b>764</b>	<b>1,169</b>	<b>405</b>	<b>764</b>	<b>1,169</b>	<b>405</b>	<b>764</b>	<b>1,169</b>

Sampling was also done in order to represent Federation of Bosnia and Herzegovina and Republic of Srpska based companies as well as large corporate companies and SMEs.

The chosen dependent variable is represented by an indicator of existence or non-existence of default for a certain company included in the sample. Based on the indicator of days of delay, companies are identified as defaulted and non-defaulted (healthy). A dichotomous variable is used to represent the dependent variable, or to separate defaulted from the healthy companies. If the value of the dichotomous dependent variable is 1 it represents a defaulted company, while the value of the dependent variable of 0 is given to a healthy company.

$$Y = \begin{cases} 1, & \text{defaulted,} \\ 0, & \text{healthy.} \end{cases} \quad (10)$$

Financial ratios are believed to be the best representatives of the financial health of one company. Even though they are not a substitute for a crystal ball, they can however summarize large quantity of financial data in order to compare financial results of different companies [38]. They are widely used in for internal management purposes, external evaluation and very often in finance research, especially in default prediction issues, as they were found to be good predictors of default in previous research. Financial ratios represent relationship between two or more financial positions and their correct interpretation can lead to better understanding of the financial state of one company [39]. They provide us with necessary information regarding company's profitability and riskiness [40].

Companies with financial problems are showing statistically significant differences in the main financial ratios from the healthy companies. Based on the previous theoretical background [7, 41], list of 31 financial ratios was chosen for the study. All of the variables were chosen to represent five main groups of financial ratios: liquidity, profitability, leverage, activity and efficiency.

Two additional dichotomous variables representing the entity in which the company is registered (FB&H or RS) and company size (corporate or small and medium enterprise) were added on the list, totaling 33 variables. Table 3 shows the used 31 financial ratios and additional two dichotomous independent variables. The most frequently used financial ratios from each of the five groups were included in the study, and calculated for all of the companies in the sample. Return on investment (ROI) was consecutively omitted from the study, due to unavailability of data regarding investments in collected financial statements of companies in the sample.

To ensure the validity in this research, several steps were initiated. Since the default prediction model creation, was the main aim of the study, detailed research methodology was constructed. Defaulted companies were detected, with a corresponding year of default occurrence. Data was used from several banks operation in Bosnia and Herzegovina to ensure that the sample represents majority of the banks. It was also important that the chosen data sample, includes companies from both entities, and all major regions of the two entities. Once the defaulted companies from both entities and most regions were identified, total NPL share was assessed. To create a sample which would represent the average Bosnia and Herzegovina NPL share, an appropriate number of healthy companies was added to the defaulted list. The sample was chosen to have a needed share of both SME and large corporate companies, as well as to represent all major regions of the two entities. Original financial data was the basis for financial ratio calculation. Choice of financial ratios, as default predictors was done on the published literature basis. To create default prediction models, financial data was collected in the way to include data up to four consecutive years prior to default for defaulted companies, and up to four consecutive years, making sure that they correspond to the years of defaulted cases.

A large sample size and high confidence level was selected to be able to generalize the results to the population. To ensure research reliability, the total data set was divided twice: on two different entities and on the basis of company size. In other words, each result was validated four times for reliability several times by the created subsets. To ensure proper level of validity and reliability only the best performance models are presented. The basis for the decision on the presentation of the best performing models are: statistical, economic and logic.

Correlation matrices were created for all five datasets in order to detect multicollinearity presence for MDA analysis. Each variable having correlation with another variable higher than 0,50 or lower than -0,50 was removed from further analysis. Variance inflation factor (VIF) and tolerance values were also used to detect multicollinearity among the predictor variables. Table 4 shows the variables removed from the five data sets due to multicollinearity.

Logistic regression and multiple discriminant analysis are used to create default prediction models, on each of the five data sets. For each of the data sets, the techniques are applied on four observed years, for which the financial data are collected. The output of this research set-up is 32 prediction models. To ensure proper level of validity and reliability only the best models are presented. The basis for the decision on the presentation of the best performing models is threefold: statistical, economic and logic criteria.

Statistical criteria consist of several different tests which create the basis for the decision on the best prediction model. Predictive ability of the model is assessed by its hit ratio. Every model has three different hit indicators: (a) healthy companies correct classification, (b) defaulted companies correct classification and (c) total model hit ratio. Depending on the type of method used, different indicators of goodness-of-fit statistics are used to compare different models. Each of the predictor variables is analyzed with its relation to the dependent variable and compared to the expected relationship prior to the model creation in order to assure its economic justification. Models are also compared on the basis of the logic of the relationship between dependent and independent variables. Only the models created with the use of different methods, which have the optimal combination of statistical indicators (hit ratios and goodness-of-fit), economic justification and logical results are presented.

The final output of the research is 8 default prediction models (marked m1 to m8). Each group of methods used will have four representing models. Models m1, m2, m3 and m4 are the optimal logistic regression models for the periods four, three, two and one years before default. Models m5, m6, m7 and m8 are the optimal multiple discriminant analysis models.

## **LOGISTIC REGRESSION MODELS**

The optimal logistic regression models are chosen for all four periods prior to default. The decision is made on the basis of the scored hit ratios represented by classification tables and goodness-of-fit statistics represented by Cox & Snell R<sup>2</sup> and Nagelkerke R<sup>2</sup>. All chosen logit models are given in Appendix C.

The first chosen model m1 representing logistic regression in the period t-4 and is chosen from the large corporate companies (COR) data set. Enter was chosen over the stepwise method in this model since it gave better predictive ability and better model fit (stepwise logit model had the predictive ability of 74,2 % and Nagelkerke R<sup>2</sup> of 0,37). The model was also tested with a classification cut off point of 0,50. After the comparison between the models created with classification cut off points of 0,50 and 0,45 the later was retained, since it predicted defaulted companies significantly better than the model with the higher classification cut off point.

The first model shows that only 4 variables are statistically significant ( $p < 0,05$ ), including 2 financial ratios, one dummy variable and a constant variable. The independent variables that are statistically significant are: return on equity, indebtedness factor, Entity Dummy and a constant.

Return on assets has a logistic coefficient B of -5,281 and exponentiated coefficient  $\exp(B)$  of 0,049 ( $p$ -value < 0,05), showing that for one unit change of the return on assets variable will reduce the odds of a default by 99 %. Indebtedness factor has a logistic coefficient B of 0,022 and exponentiated coefficient  $\exp(B)$  of 1,023 ( $p$ -value < 0,05), showing that for one unit change of the indebtedness factor variable will increase the odds of a default by 2 %. The model shows that companies registered in Federation of Bosnia and Herzegovina have 80 % lower odds of defaulting than companies registered in Republic of Srpska. The model has Wald statistic value of the Omnibus Test of Model Coefficients of 160,207 ( $p = 0,000$ ), and it can be concluded that the proposed model fits the data well. Hosmer and Lemeshow test compares the fitted expected and actual values by groups. Hosmer and Lemeshow test has an insignificant Wald statistic of 3,384 ( $p = 0,908$ ) also suggesting and confirming Omnibus Test of Model Coefficients that the created model fit at a desired level. It can be concluded that the model has satisfactory goodness-of-fit confirmed by both chosen statistics.

The  $-2 \log$  likelihood of the final model has a value of 437,234 and has decreased significantly from the base model in which the  $-2 \log$  likelihood amounted 533,827. It can be concluded that adding statistically significant variables (return on equity, indebtedness factor, Entity Dummy) improved the model  $\chi^2(3, N = 442) = 96,593, p < 0,001$ . Two additional descriptive measures of goodness-of-fit presented in Table 16 are Cox and Snell  $R^2$  and Nagelkerke  $R^2$ , as they have values of 0,304 and 0,410, respectively indicating also fairly good goodness-of-fit. The two  $R^2$  statistics show the amount of variability explained by the model. This can be considered as a high level of goodness-of-fit since the data used for the model is four years distant from default occurrence. Higher values of the two  $R^2$  indicators suggest a better model goodness-of-fit.

The second chosen model m2 representing logistic regression in the period  $t - 3$  is created from the large corporate companies (COR) data set. Enter was chosen over the stepwise method in this model since it gave better predictive ability and better model fit (stepwise logit model had the predictive ability of 77,4 % and Nagelkerke  $R^2$  of 0,44). The model was also tested with a classification cut off point of 0,45. After the comparison between the models created with classification cut off points of 0,50 and 0,45 the model with classification cut off of 0,50 was retained, since it predicted healthy companies significantly better than the model with the higher classification cut off point. There is no significant difference of defaulted companies predictive ability between the two compared models.

The second model shows that 6 variables are statistically significant ( $p < 0,050$ ), including 4 financial ratios, one dummy variable and a constant variable. The independent variables that are statistically significant are: short term assets to total assets, return on assets, shareholder equity ratio, account payables days, Entity Dummy and a constant.

Short term assets to total assets has a logistic coefficient B of -3,294 and exponentiated coefficient  $\exp(B)$  of 0,211 ( $p$ -value = 0,00), showing that for one unit change of the short term assets to total assets variable will increase the odds of a default by 88 %. Return on assets has a logistic coefficient B of -11,090 and exponentiated coefficient  $\exp(B)$  of 0,000 ( $p$ -value < 0,05), showing that for one unit change of the return on assets variable will decrease the odds of a default by 100 %. Shareholder equity ratio has a logistic coefficient B of -2,803 and exponentiated coefficient  $\exp(B)$  of 0,061 ( $p$ -value = 0,00), showing that for one unit change of the shareholder equity ratio variable will decrease the odds of a default by 94 %. Account payables days has a logistic coefficient B of -0,002 and exponentiated coefficient  $\exp(B)$  of 0,997 ( $p$ -value < 0,05), showing that for one unit change of the account payables days variable will decrease the odds of a default by less than 1 %. The model three years prior to default shows that companies registered in Federation of Bosnia and

Herzegovina have 79 % lower odds of defaulting than companies registered in Republic of Srpska. The model has Wald statistic value of the Omnibus Test of Model Coefficients of 220,275 ( $p = 0,000$ ), and it can be concluded that the proposed model fits the data well. Hosmer and Lemeshow test however has a significant Wald statistic of 16,419 ( $p = 0,037$ ) unlike Omnibus Test of Model Coefficients showing that the created model does not fit at a desired level. Since the Hosmer and Lemeshow test shows the  $p$ -value close to the insignificance level of 0,50, and that Omnibus Test of Model Coefficients has a significant  $p$ -value it can be concluded that the model has satisfactory goodness-of-fit confirmed by one of the chosen statistics. Since all of the other models tested on the  $t - 3$  data had a significant Hosmer and Lemeshow test, the model created from the corporate data set is presented, having better predictive ability and goodness-of-fit.

The  $-2 \log$  likelihood of the final model has a value of 399,887 and has decreased significantly from the base model in which the  $-2 \log$  likelihood amounted 555,937. It can be concluded that adding statistically significant variables (short term assets to total assets, return on assets, shareholder equity ratio, account payables days, Entity Dummy) improved the model significantly  $\chi^2(5, N = 458) = 156,050, p < 0,001$ . Additional descriptive measures of goodness-of-fit are Cox and Snell  $R^2$  and Nagelkerke  $R^2$ , as they have values of 0,385 and 0,515, respectively indicating also good goodness-of-fit. The two  $R^2$  statistics show the amount of variability explained by the model. It can be interpreted that shown by Cox and Snell  $R^2$  the presented model explains 38,5 % of the variance, while the Nagelkerke  $R^2$  shows that the model explains 51,5 % of the variance of default. This can be considered as a high level of goodness-of-fit since the data used for the model is three years distant from default occurrence.

The third chosen model m3 representing logistic regression in the period  $t - 2$  is from the large corporate companies (COR) data set. Stepwise was chosen over the enter method in this model since it gave better predictive ability and better model fit (enter logit model had the predictive ability of 81,1 % and Nagelkerke  $R^2$  of 0,44). The model was also tested with a classification cut off point of 0,45. After the comparison between the models created with classification cut off points of 0,50 and 0,45 the model with classification cut off of 0,50 was retained, since it predicted healthy companies significantly better than the model with the higher classification cut off point and there was no significant difference of defaulted companies predictive ability between the two compared models.

The model shows that 6 variables are statistically significant ( $p < 0,050$ ), including 5 financial ratios and one dummy variable. Constant variable has an insignificant  $p$ -value. The independent variables that are statistically significant are: coefficient of financial stability, return on assets, liabilities to total asset ratio, total assets turnover ratio, account receivables days and Entity Dummy.

Coefficient of financial stability has a logistic coefficient B of ,481 and exponentiated coefficient  $\exp(B)$  of 1,618 ( $p$ -value  $< 0,05$ ), showing that for one unit change of the coefficient of financial stability variable will increase the odds of a default by 62 %. Return on assets has a logistic coefficient B of -16,523 and exponentiated coefficient  $\exp(B)$  of 0,000 ( $p$ -value = 0,00), showing that for one unit change of the return on assets variable will decrease the odds of a default by 100 %. Liabilities to total asset ratio has a logistic coefficient B of 0,009 and exponentiated coefficient  $\exp(B)$  of 1,009 ( $p$ -value  $< 0,05$ ), showing that for one unit change of the liabilities to total asset ratio variable will increase the odds of a default by 1 %. Total assets turnover ratio has a logistic coefficient B of -0,693 and exponentiated coefficient  $\exp(B)$  of 0,500 ( $p$ -value  $< 0,05$ ), showing that for one unit change of the total assets turnover ratio variable will decrease the odds of a default by 50 %. Account receivables days has a logistic coefficient B of 0,002 and exponentiated coefficient  $\exp(B)$

of 1,002 ( $p$ -value < 0,05), showing that for one unit change of the account receivables days variable will increase the odds of a default by less than 1 %.

The chosen model included the dummy variable coding companies coming from different entities. The model two years prior to default shows that companies registered in Federation of Bosnia and Herzegovina have 77 % (logistic coefficient B equals  $-1,482$ ) lower odds of defaulting than companies registered in Republic of Srpska. The model has Wald statistic value of the Omnibus Test of Model Coefficients of 191,095 ( $p = 0,000$ ), and it shows that the proposed model fits the data well. Hosmer and Lemeshow test has an insignificant Wald statistic of 12,348 ( $p = 0,132$ ) and confirms the Omnibus Test of Model Coefficients, showing that the created model fits at a desired level. It can be concluded that the model has satisfactory goodness-of-fit confirmed by both chosen statistics. The model fit is estimated with the value of  $-2$  times the log of the likelihood known as  $-2$  Log likelihood. The  $-2$  Log likelihood of the final model has a value of 424,112 and has decreased significantly from the base model in which the  $-2$  Log likelihood amounted 511,711. The total difference of the two  $-2$  Log likelihood statistics is 87,599. It can be concluded that adding statistically significant variables (coefficient of financial stability, return on assets, liabilities to total asset ratio, total assets turnover ratio, account receivables days and Entity Dummy) improved the model significantly  $\chi^2(6, N = 454) = 87,599, p < 0,001$ . Two additional descriptive measures of goodness-of-fit Cox and Snell  $R^2$  and Nagelkerke  $R^2$  have values of 0,344 and 0,463, respectively indicating also good goodness-of-fit. Cox and Snell  $R^2$  and Nagelkerke  $R^2$  improved significantly as they amounted 0,204 and 0,275, respectively, in the base model. The two  $R^2$  statistics show the amount of variability explained by the model. It can be interpreted that shown by Cox and Snell  $R^2$  the presented model explains 34,4 % of the variance, while the Nagelkerke  $R^2$  shows that the model explains 46,3 % of the variance of default. This can be considered as a relatively high level of goodness-of-fit since the data used for the model is two years distant from default occurrence.

The fourth chosen model m4 representing logistic regression in the period  $t - 1$  is from the large corporate companies (COR) data set. Stepwise was chosen over the enter method in this model since it gave better predictive ability and better model fit (enter logit model had the predictive ability of 84,7 % and Nagelkerke  $R^2$  of 0,53). The model was also tested with a classification cut off point of 0,45. After the comparison between the models created with classification cut off points of 0,50 and 0,45 the model with classification cut off of 0,50 was retained, since it predicted healthy companies significantly better than the model with the higher classification cut off point and there was no significant difference of defaulted companies predictive ability between the two compared models.

The model shows that 5 variables are statistically significant ( $p < 0,050$ ), including 4 financial ratios and one dummy variable. Constant variable has an insignificant  $p$ -value. The independent variables that are statistically significant are: coefficient of financial stability, return on assets, debt asset ratio, total assets turnover ratio and Entity Dummy.

Coefficient of financial stability has a logistic coefficient B of 0,174 and exponentiated coefficient  $\exp(B)$  of 1,187 ( $p$ -value = 0,00), showing that for one unit change of the coefficient of financial stability variable will increase the odds of a default by 19 %. Return on assets has a logistic coefficient B of  $-8,255$  and exponentiated coefficient  $\exp(B)$  of 0,000 ( $p$ -value = 0,00), showing that for one unit change of the return on assets variable will decrease the odds of a default by 100 %. Debt asset ratio has a logistic coefficient B of 2,495 and exponentiated coefficient  $\exp(B)$  of 12,126 ( $p$ -value = 0,00), showing that for one unit change of the debt asset ratio variable will increase the odds of a default by more than 1,000 %. Total assets turnover ratio has a logistic coefficient B of  $-1,974$  and exponentiated coefficient  $\exp(B)$  of

0,139 ( $p$ -value = 0,00), showing that for one unit change of the total assets turnover ratio variable will decrease the odds of a default by 86 %.

The chosen model included the dummy variable coding companies coming from different entities. The model one years prior to default shows that companies registered in Federation of Bosnia and Herzegovina have 81 % (logistic coefficient B of -1,676) lower odds of defaulting than companies registered in Republic of Srpska. The model has Wald statistic value of the Omnibus Test of Model Coefficients of 246,049 ( $p$  = 0,000), and it shows that the proposed model fits the data well. Hosmer and Lemeshow test has an insignificant Wald statistic of 15,245 ( $p$  = 0,055) and confirms the Omnibus Test of Model Coefficients, showing that the created model fits at a desired level. It can be concluded that the model has satisfactory goodness-of-fit confirmed by both chosen statistics. The model fit is estimated with the value of -2 times the log of the likelihood known as -2 Log likelihood. The -2 Log likelihood of the final model has a value of 363,314 and has decreased significantly from the base model in which the -2 Log likelihood amounted 469,258. The total difference of the two -2 Log likelihood statistics is 105,944. It can be concluded that adding statistically significant variables (coefficient of financial stability, return on assets, liabilities to total asset ratio, total assets turnover ratio, account receivables days and Entity Dummy) improved the model significantly  $\chi^2(5, N = 452) = 105,944, p < 0,001$ .

Two additional descriptive measures of goodness-of-fit Cox and Snell R<sup>2</sup> and Nagelkerke R<sup>2</sup> have values of 0,420 and 0,567, respectively indicating also good goodness-of-fit. Cox and Snell R<sup>2</sup> and Nagelkerke R<sup>2</sup> improved significantly as they amounted 0,267 and 0,360, respectively, in the base model. The two R<sup>2</sup> statistics show the amount of variability explained by the model. It can be interpreted that shown by Cox and Snell R<sup>2</sup> the presented model explains 42,0 % of the variance, while the Nagelkerke R<sup>2</sup> shows that the model explains 56,7 % of the variance of default.

The key goal of each of created prediction models is to predict the data behavior to the maximum possible extent. The next table compared the predictive abilities, through hit ratios, of the four chosen logistic regression models.

**Table 3.** Logit model hit ratio comparison. Source: author's calculations.

Logit hit ratio comparison				
	m1 ( $t - 4$ ), %	m2 ( $t - 3$ ), %	m3 ( $t - 2$ ), %	m4 ( $t - 1$ ), %
Healthy	77,90	84,07	83,15	86,30
Defaulted	70,00	76,06	78,61	82,97
<b>Overall correct</b>	<b>74,40</b>	<b>80,79</b>	<b>81,28</b>	<b>84,96</b>

## MULTIPLE DISCRIMINANT ANALYSIS MODELS

All multiple discriminant analysis models were adjusted in order to fulfil all statistical assumptions including normal distribution, homogeneity of variances/covariance, correlations between means and variances and multicollinearity. All chosen logit models are given in Appendix D.

The first chosen model m5 representing MDA in the period  $t - 4$  is created from the large corporate companies (COR) data set. The model was created using seven model creation steps including creation of the base discriminant model, checking the database for outliers, testing of variables for normality assumption, substitution of variables not fulfilling normality assumption with transformed variables, checking the variables for multicollinearity, checking the model for homogeneity of variances/covariance assumption.

The model has Wilks' lambda highly significant ( $p < 0,000$ ) and has a value of 0,754 shows relatively low separation between defaulted and healthy companies, as 75,4 % of variability is not explained by the model. The  $\chi^2$  statistic tests whether the canonical correlation of the function is equal to zero, or whether the model has any discriminating power. The null hypothesis of the  $\chi^2$  statistic is that the model has no discriminating power. The  $\chi^2$  statistic's significance level is calculated by the  $p$ -value. The presented model has a  $\chi^2$  of 117,190 ( $p = 0,000$ ). The Box's M statistic has a value of 519,355 with a significant  $p$ -value (0,000) which means that the null hypothesis is not rejected and the assumption of equal dispersion is violated. The large sample size however makes this violation not too important for the further model interpretation and classification ability. The model consists of seven predictor variables including: net working capital, return of assets, net profit margin, indebtedness factor, total assets turnover ratio, account receivables turnover ratio and a dummy variable indicating an entity where the company is registered. The model shows that variables return on assets and EntityDummy have the highest coefficients and strong impact on the default prediction.

The second chosen model m6 representing MDA in the period  $t - 3$  is from the large corporate companies (COR) data set. The model has Wilks' lambda highly significant ( $p < 0,000$ ) and has a value of 0,741 shows relatively low separation between defaulted and healthy companies, as 74,1 % of variability is not explained by the model. The  $\chi^2$  statistic tests whether the canonical correlation of the function is equal to zero, or whether the model has any discriminating power. The null hypothesis of the  $\chi^2$  statistic is that the model has no discriminating power. The  $\chi^2$  statistic's significance level is calculated by the  $p$ -value. The presented model has a  $\chi^2$  of 128,270 ( $p = 0,000$ ). The Box's M statistic has a value of 883,232 with a significant  $p$ -value (0,000) which means that the null hypothesis is not rejected and the assumption of equal dispersion is violated. The large sample size however makes this violation not too important for the further model interpretation and classification ability.

The model consists of five predictor variables including: return of assets, total assets turnover ratio, liabilities to total asset ratio, return on equity, and financial efficiency ratio. The model shows that variables return on assets and total assets turnover ratio have the highest coefficients and strong impact on the default prediction.

The third chosen model m7 representing MDA in the period  $t - 2$  is from the Federation of Bosnia and Herzegovina (FB&H) data set. This model initially included 756 cases, before the variables transformation. In the model creation procedure, 448 cases were excluded due to missing variables, giving the total of 308 valid cases used in the model creation procedure. The model has Wilks' lambda highly significant ( $p < 0,000$ ) and has a value of 0,691 shows relatively low separation between defaulted and healthy companies, as 69,1 % of variability is not explained by the model. The  $\chi^2$  statistic tests whether the canonical correlation of the function is equal to zero, or whether the model has any discriminating power. The null hypothesis of the  $\chi^2$  statistic is that the model has no discriminating power. The  $\chi^2$  statistic's significance level is calculated by the  $p$ -value. The presented model has a  $\chi^2$  of 112,558 ( $p = 0,000$ ). The Box's M statistic has a value of 5,607 with an insignificant  $p$ -value (0,478) which means that the null hypothesis is rejected and the homogeneity of variances/covariance assumption fulfilled.

The model consists of three predictor variables including: return of assets, net profit margin and liabilities to total asset ratio and all with high coefficients and strong impact on the default prediction. All of the included variables are transformed using their logarithmic value.

The fourth chosen model m8 representing MDA in the period  $t - 1$  is from the Federation of Bosnia and Herzegovina (FB&H) data set. The model initially included 756 cases. This model has highly significant Wilks' lambda ( $p < 0,000$ ) and has a value of 0,607 shows

relatively low separation between defaulted and healthy companies, as 60,7 % of variability is not explained by the model. The  $\chi^2$  statistic tests whether the canonical correlation of the function is equal to zero, or whether the model has any discriminating power. The null hypothesis of the  $\chi^2$  statistic is that the model has no discriminating power. The  $\chi^2$  statistic's significance level is calculated by the p-value. The presented model has a  $\chi^2$  of 367,675 ( $p = 0,000$ ). The Box's M statistic has a value of 3008,662 with a significant  $p$ -value (0,000) which means that the null hypothesis is not rejected and the assumption of equal dispersion is violated. The large sample size however makes this violation not too important for the further model interpretation and classification ability.

This model consists of nine predictor variables including: short term assets to total assets return of assets, return on assets, debt asset ratio, total assets turnover, account receivables days, account payables days, main activities efficiency ratio and financial efficiency ratio. The model shows that variables main activities efficiency ratio, debt asset ratio and return on assets have the highest coefficients and strong impact on the default prediction.

Table 4 compares the predictive abilities, through hit ratios, of the four chosen multiple discriminant analysis models. Table 5 gives the comparative analysis of obtained models' predictive abilities and used predictor variables.

**Table 4.** MDA model hit ratio comparison. Source: author's calculations.

MDA hit ratio comparison				
	<b>m5 (t - 4), %</b>	<b>m6 (t - 3), %</b>	<b>m7 (t - 2), %</b>	<b>m8 (t - 1), %</b>
Healthy	68,80	69,00	69,62	84,40
Defaulted	74,87	85,40	83,73	76,45
<b>Overall correct</b>	<b>71,40</b>	<b>75,98</b>	<b>73,80</b>	<b>81,45</b>

**Table 5.** Logit and MDA model hit ratio comparison. Source: author's calculations.

Logit hit ratios				
	<b>m1 (t-4)</b>	<b>m2 (t-3)</b>	<b>m3 (t-2)</b>	<b>m4 (t-1)</b>
Healthy	77,90%	84,07%	83,15%	86,30%
Defaulted	70,00%	76,06%	78,61%	82,97%
<b>Overall % correct</b>	<b>74,40%</b>	<b>80,79%</b>	<b>81,28%</b>	<b>84,96%</b>
Model variables	ROA, IF, EntityDummy	STATTA, ROA, SER, ALD, EntityDummy	CFS, ROA, LTTAR, TAT, ARD, EntityDummy	CFS, ROA, DAR, TAT, EntityDummy
MDA hit ratios				
	<b>m5 (t-4)</b>	<b>m6 (t-3)</b>	<b>m7 (t-2)</b>	<b>m8 (t-1)</b>
Healthy	68,80%	78,71%	69,62%	84,40%
Defaulted	74,87%	84,49%	83,73%	76,45%
<b>Overall % correct</b>	<b>71,40%</b>	<b>81,19%</b>	<b>73,80%</b>	<b>81,45%</b>
Model variables	ROA, TAT, MAEF, NPM, EntityDummy, NWC, ARTR, IF	ROA, TAT, LTTAR, FER, ROE	ROA, NPM, LTTAR	ROA, TAT, MAEF, FER, STATT, ARD, DAR, ALD, ROE

## CONCLUSIONS

This article investigated the bankruptcy prediction on banking market in Bosnia and Herzegovina and its constitutional entities using logistic regression and multiple discriminant analysis. Problem of finding an appropriate tool which would replace human assessment in classifying companies into good and bad buckets has been one of the main interests on risk

management researchers for a long time [42]. The main reason for such interest in this topic lays in the increasing default rates which endanger profitability of financial institutions.

This research is based on the detailed review of the relevant literature. All of the reviewed literature treats risk modeling, mainly models predicting default occurrence among legal entities. Literature gives a wide overview of models created using different data sets and different model-creation techniques. Default was also assessed from the theoretical aspect, considering definitions given by Basel Committee, Federal Banking Agency and Banking Agency of Republic of Srpska. Main criteria for a company to be considered defaulted are companies being in delay of debt servicing for more than 90 days.

Banking sector of Bosnia and Herzegovina was analyzed, as the sample for the research was created. Initial sample includes companies from both B&H entities, as they are presumed as almost separate banking markets. Data for the study was collected from several data bases, independently for default data and corresponding financial data, as no integral data base exists in Bosnia and Herzegovina. Defaulted companies were detected, with a corresponding year of default occurrence. Data was used from several banks operation in Bosnia and Herzegovina to ensure that the sample represents majority of the banks. Financial ratios, as main default predictors were chosen, based on the relevant literature. The research includes 31 financial and 2 dummy predictor variables, which were collected for all sampled companies, up to four periods prior to default. They were matched with default data, indicating whether a company is defaulted or healthy. The final sample included 1148 companies for the period  $t - 4$ , and 1169 companies for the periods  $t - 3$ ,  $t - 2$  and  $t - 1$ .

This study has a main purpose to assess the probability of default occurrence on the banking market from Bosnia and Herzegovina. In other words the main purpose of the study is predict credit default, or to create a prediction model that distinguishes defaulted and non-defaulted companies, based on the financial data obtained from their financial statements using multi-method approach. The methods used in this study are: logistic regression (logit) and multiple discriminant analysis (MDA).

The outcome of the study is a set of default prediction models created using four different techniques on five different groups of data sets: on a country level, on constitutional entities level, SMEs and large corporate companies.

The results show that the created models have high predictive ability. Among the created models, some variables seem to be more influential on the default prediction issue than the others. Observing logistic regression models, return on assets is statistically significant in all four periods prior to default, having very high regression coefficients, or high impact on the model's ability to predict default. Entity dummy representing the companies coming either from Federation of Bosnia and Herzegovina or Republic of Srpska, is also statistically significant in all four periods prior to default, with its negative regression coefficients showing that companies registered in Federation of Bosnia and Herzegovina in general have lower odds of defaulting than companies registered in Republic of Srpska. Variables coefficient of financial stability, total assets turnover ratio are included in two out of the four models.

Among four logistic regression models, some variables are more influential on the default prediction than the others. Observing logistic regression models, return on assets is statistically significant in all four periods prior to default, having very high regression coefficients, or high impact on the model's ability to predict default. Entity dummy representing the companies coming either from Federation of Bosnia and Herzegovina or Republic of Srpska, is also statistically significant in all four periods prior to default, with its negative regression coefficients showing that companies registered in Federation of Bosnia and Herzegovina in general have lower odds of defaulting than companies registered in

Republic of Srpska. Variables coefficient of financial stability, total assets turnover ratio are included in two out of the four models.

Best performing multiple discriminant analysis default prediction models were selected based on scored hit ratios represented by classification tables, eigenvalues, canonical correlations and Wilks' lambda values of created MDA models, as well as on the strength and direction of the impact of chosen predictors on default. Two models were created using large corporate data sets, while the other two were created on the basis of Federation of Bosnia and Herzegovina data sets.

In the four multiple discriminant analysis models return on assets (or its logarithmic transformation) is the only predictor variable, present in all four MDA models, having a high impact on the model's predictive ability and on default. Total assets turnover ratio is included in three out of four models. Main activities efficiency ratio, net profit margin, liabilities to total asset ratio and financial efficiency ratio are included in two models.

Credit default predictive ability differs between logistic regression and multiple discriminant analysis. Logistic regression exhibited better predictive ability than multiple discriminant analysis. Based on the models created it can be confirmed that there is no significant difference between credit default prediction of large corporate companies and SMEs. The study also showed that<sup>1</sup> there is no significant difference between credit default prediction models for companies in Federation of Bosnia and Herzegovina and in Republic of Srpska, with a remark that some models showed that companies registered in Republic of Srpska are more likely to default, and carry higher credit risk accordingly, than companies registered in Federation of Bosnia and Herzegovina.

It is expected that this research motivates another researchers and practitioners to give more attention to a very complex issue of risk management and more particularly default prediction in Bosnia and Herzegovina. This area has been fairly undeveloped in practice and almost not considered in business research areas in Bosnia and Herzegovina so far.

## **REMARKS**

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<sup>2</sup>State agency for intermediation, information and financial services (Agencija za posredničke, informatičke i finansijske usluge a.d. Banja Luka).

## APPENDICES

### Appendix A

**Table 6.** Dependent and independent variables. Source: author's data.

Group	Ratio	Equation	Abbreviation	Expected default impact
LIQUIDITY	Current liquidity	Current assets/current liabilities	CL	+
	Acid test	(Current assets-inventories)/current liabilities	AT	+
	Quick liquidity ratio	Cash/current liabilities	QLR	+
	Net working capital	Current assets-current liabilities	NWC	+
	Short term assets to total assets	Short term assets/total assets	STATTA	+
	Coefficient of financial stability	Long term assets/(equity+long term liabilities)	CFS	+
PROFITABILITY	Return on assets	Net result/total assets	ROA	+
	Return on equity	Net result/total equity	ROE	+
	Return on investment	Net result/investments	ROI	+
	Net profit margin	Net result/total revenues	NPM	+
	Gross profit margin	Gross result/total revenues	GPM	+
LEVERAGE	Indebtedness factor	Total liabilities / (retained earnings+depreciacion)	IF	-
	Debt asset ratio	Total financial liabilities/total assets	DAR	-
	Interest coverage	EBIT/interest expences	IC	+
	Shareholder equity ratio	Equity/total assets	SER	+
	Liabilities to total asset ratio	Total liabilities/total assets	LTTAR	-
	Coverage ratio I	Equity/long term assets	CR I	+
	Gross interest coverage	Gross result/interest expences	GIC	+
Group	Ratio	Equation	Abbreviation	Expected default impact
ACTIVITY	Total assets turnover ratio	Total revenues/total assets	TAT	+
	Long-term assets turnover ratio	Total revenues/long term assets	LTAT	+
	Short-term assets turnover ratio	Total revenues/short term assets	STAT	+
	Inventories turnover ratio	COGS/inventories	ITR	+
	Account receivables turnover ratio	Total revenues/ account receiveables	ARTR	+
	Account payables turnover ratio	COGS/account payables	ALTR	-
	Inventory days	365/inventories turnover ratio	ID	-
	Account receivables days	365/account receivables turnover ratio	ARD	-
	Account payables days	365/account payables turnover ratio	ALD	+
EFFICIENCY	Total efficiency ratio	Total revenues/total expenditures	TEF	+
	Main activities efficiency ratio	Main activities revenues /Main activities expenditures	MAEF	+
	Extraordinary activities efficiency ratio	Extraordinary revenues /Extraordinary expenditures	EAEF	+
	Financing efficiency ratio	Financial revenues/financial expenditures	FER	+
CAT	Entity	FB&H/RS	ENTITY	neutral
	Size	COR/SME	SIZE	neutral

### Appendix B

**Table 7.** MDA multicollinear variables removed. Source: author's calculations.

Variable removed	<i>t - 4</i>	<i>t - 3</i>	<i>t - 2</i>	<i>t - 1</i>
AT	×	×	×	×
GIC	×	×		×
TEF	×		×	×
SER	×			×
DAR		×	×	
GMP		×		
IC			×	
QLR				×

## Appendix C

**Table 8.** Logistic regression models. Source: author's calculations.

Predictor	m1 (t-4)		m2 (t-3)		m3 (t-2)		m4 (t-1)	
	B	sig.	B	sig.	B	sig.	B	sig.
CL	-,029	,354	-,046	,554				
QLR	,149	,611	,273	,505				
NWC	,000	,180	,000	,396				
STATTA	-,969	,293	-2,125	,033**				
CFS	-,187	,491	-,394	,103	,481	,016**	,174	,009***
ROA	-5,281	,049**	-11,090	,001***	-16,523	,000***	-8,255	,000***
ROE	-,070	,549						
NPM	,322	,221	,051	,317				
IF	,022	,000***	-,001	,683				
DAR	,603	,370					2,495	,000***
IC	-,006	,310	-,017	,418				
SER			-2,803	,000***				
LT TAR	-,005	,360	,008	,163	,009	,027**		
CRI	,085	,244	,040	,211				
TAT	-,442	,082	-,483	,154	-,693	,001***	-1,974	,000***
LTAT	-,004	,556						
STAT	,014	,868	-,206	,092				
ITR	-,002	,673	,001	,624				
ARTR	,017	,055	-,001	,606				
ALTR	-,018	,149	-,002	,503				
ID	,002	,231	,002	,094				
ARD	,002	,330	,002	,067	,002	,036**		
ALD	-,003	,066	-,003	,017**				
MAEF	-,715	,213	,360	,606				
EAEF	-,014	,093	,014	,201				
FER	,029	,733	-,320	,348				
EntityDummy(1)	-1,630	,000***	-1,555	,000***	-1,482	,000***	-1,676	,000***
Constant	1,820	,019**	3,294	,002**	,203	,520	-,268	,530
<b>Omnibus Tests of Model Coefficients</b>	160,207	,000***	191,095	,000***	191,095	,000***	246,049	,000***
<b>Hosmer and Lemeshow Test</b>	3,384	,908	12,458	,132	12,458	,132	15,245	0,055
<b>-2 Log likelihood</b>	437,234		399,887		424,112		363,314	
<b>Cox &amp; Snell R Square</b>	,304		,382		,344		,420	
<b>Nagelkerke R Square</b>	,410		0,515		0,463		,567	

\* $p$ -value < 0,01

\*\* $p$ -value < 0,05

\*\*\* $p$ -value < 0,1

## Appendix D

**Table 9.** Multiple discriminant analysis models. Source: author's calculations.

MDA model variable comparison (Canonical discriminant coefficients)				
Variable	m5 (t-4)	m6 (t-3)	m7 (t-2)	m8 (t-1)
NWC	0,000			
STATTA				-0,154
ROA	-5,166	12,499		-1,821
Log_ROA			-2,423	
ROE		-0,392		
NPM	0,178			
Log_NPM			1,898	
IF	0,012			
DAR				1,909
LTTAR		-0,008		
Log_LTTAR			1,147	
TAT	-0,359	0,632		-0,388
ARTR	0,120			
ARD				0,001
MAEF				-1,169
FER		0,242		-0,014
EntityDummy	1,463			
Segment Dummy				0,895
Constant	-0,368	-0,858	-1,337	-0,070

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# **PROCJENA STATUSA NEISPUNJAVANJA KREDITNIH OBVEZA KORIŠTENJEM LOGISTIČKE REGRESIJE I VIŠESTRUKE ANALIZE DISKRIMINANTE: EMPIRIJSKI PODACI ZA BOSNU I HERCEGOVINU**

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## **SAŽETAK**

Cilj ovog rada je procijeniti status neispunjavanja obveza u kreditnom predviđanje na bankarskom tržištu Bosne i Hercegovine te bankarskim tržištima njenih konstitutivnih entiteta (Federacija Bosne i Hercegovine te Republika Srpska). Sposobnost klasificiranja tvrtki u različite unaprijed definirane grupe, odnosno nalaženje prikladnog alata za zamjenu ljudske procjene pri klasificiranju tvrtki, već je duže vrijeme jedan od glavnih interesa istraživača upravljanja rizikom. Istraživana je sposobnost za polazno predviđanje i pripadna točnost pomoću tradicionalnih statističkih metoda logistickog regresije (logit) i višestrukog diskriminantnog analizom. Njihove su sposobnosti predviđanja uspoređene. Rezultati pokazuju visoku sposobnost predviđanja postavljenih modela. Za logit-modele neke varijable su utjecajnije u predviđanjima od drugih. Povrat na imovinu statistički je značajan u sva četiri razdoblja prije polaznog, karakteriziraju ga visoki koeficijenti regresije ili veliki utjecaj na sposobnost modela da predviđa status neispunjavanja obveza. Slični rezultati dobiveni su za modele višestruke diskriminantne analize. Također je ustanovljeno da se sposobnost predviđanja razlikuje između logističke regresije i višestruke diskriminantne analize.

## **KLJUČNE RIJEČI**

Bosna i Hercegovina, predikcija statusa neispunjavanja obveza, logistička regresija, višestruka diskriminantna analiza, bankarstvo

# BUSINESS SAMPLE SURVEY MEASUREMENT ON STATISTICAL THINKING AND METHODS ADOPTION: THE CASE OF CROATIAN SMALL ENTERPRISES

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## ABSTRACT

The objective of this research is to investigate attitudes of management in Croatian small enterprises that use statistical methods towards statistical thinking in order to gain an insight into related issues. The research was conducted in 2013 using a web survey with a random sample of 631 Croatian small enterprises, but this paper focuses only on those enterprises that use statistical methods. In order to get detailed information, a complex stratified sample survey design was used. In the analysis, chi-square tests of independence were used. In the statistical tests of proportion, the nonresponse adjustment factors as weights and weighted proportions were used. It has been shown that the vast majority of Croatian small enterprises (65,93 %) do not even use statistical methods in their business. On the other hand, the enterprises which use statistical methods have recognized the value and capabilities of statistical methods use. The research has shown that the vast majority of enterprises do not use statistical methods due to administrative reasons. In spite of using statistical methods as a supporting tool in the decision-making process in very important and key business cases, Croatian small enterprises admitted the lack of statistical methods use in their business. Also, investments into the statistical methods use are very scarce. This has led to employees' low statistical methods use knowledge level. The statistical methods use led to better business results in more than 90 % of small enterprises. It has been shown that statistical methods use effects on business results have on average a 6-12 months lag. This research leads to the conclusion that more efforts should be put into development of statistical thinking in these enterprises and familiarizing them with statistical methods use, with the aim of increasing their use and improving business results.

## KEY WORDS

statistical thinking, business survey, complex sample survey design, weighted stratified proportion estimator, chi-square tests of independence

## CLASSIFICATION

JEL: C12, C42, M21

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## **INTRODUCTION**

Statistical thinking is a philosophy of learning and action based on the following principles: all work occurs in a system of interconnected processes; variation exists in all processes, and understanding and reducing variation are keys to success [1]. The development of statistical thinking, which began in the 1990s, is the next step in the evolution of the statistics discipline [2]. According to Moore [3; p.134] statistical thinking has become the most important part of inquiry. Box [4] agrees with that and emphasizes the need to develop a statistical way of thinking and to change the approach to problems. According to him, these developments and changes are needed because of the intensive computer use in dealing with different business problems. Despite the increased need for statistical knowledge, which resulted in an increased number of statistical subjects and students who are interested in statistics [5-7], statistics has been viewed by students as difficult and unpleasant to learn, and by instructors as frustrating and unrewarding to teach [8; p.4]. An inadequate level of computers use due to insufficient institutions' funds and a general aversion of students to statistics and statistical thinking are seen by Cobanovic [9] as the main barriers to the further development and improvement of education in the application of statistical methods.

Presented situation in statistics education reflects on statistics use and statistical thinking in enterprises. According to Dransfield, Fisher and Vogel [10] the statistical methods use has an important role in the measurement of enterprises' organizational effectiveness, which is of fundamental importance for achieving business excellence. Montgomery [11] agrees that the statistical methods use in enterprises has become necessary. He also notes that, since the 1980s, a significant progress has been made not only in the use of statistical methods in enterprises, but also in their development. But research from different countries, such as Canada [12], Croatia [13-17], the Czech Republic [18], Finland [19], Germany [20], Great Britain [19, 21, 22], Kosovo [23], Malaysia [24], Portugal [19], South Africa [25-27], Spain [20], Sweden [28-31] and the United States [32], has shown that statistical methods and statistical thinking are used only in a small number of enterprises and that in most cases enterprises use only the simplest statistical methods and approaches.

It is indicative that enterprises slowly accept and implement statistical methods in their business. According to Makrymichalos et al. [33] the main reasons and barriers to further development and increase of the statistical methods usage level in enterprises are: different opinions on statistical methods of enterprises and their employees; inadequate education at universities in the field of statistical methods use; managers' fear of the statistical methods use. Deleryd [34] has formed four groups of reasons for seldom statistical methods application: problems in management; conservative personal employees' attitudes; practical problems; methodological problems. Antony et al. [18] consider that the reasons for scarce statistical methods use are the following: a lack of quality management's awareness of general statistics methods principles; a lack of awareness about the statistical methods use importance and the resulting benefits from their implementation; academic institutions provide inadequate education on the statistical methods use in enterprises; managers' insistence on one-factor approach application to the process optimization; inadequate skills and competence in the advanced statistical methods application field; a negative attitude towards quality improvement and process optimization strategies; a lack of funds to run a pilot study. Another empirical research has shown that the main reasons for a lack of statistical methods use include low managers' commitment and poor statistical background of employees in enterprises [35]. Antony [36] concludes that there is a huge difference between the current level of statistical methods use knowledge, and the level required for successful solving of enterprises' problems.

On the other hand, enterprises do not use statistical methods because: an enterprise is already considered as successful; a lack of awareness about the benefits of applying these methods; the lack of resources; time constraints; and managers' decisions [21]. More advanced statistical methods are not being used because enterprises are not aware of their existence and potential, or they are not ready and trained for their use [25].

Small enterprises are the base of each economy. The better business results small enterprises in a country have, the better the country's economy and prosperity is. Previous research has shown that statistical methods use and statistical thinking in general can improve enterprises' business results. Because of that, it is very interesting to research what the position of statistical thinking in modern Croatian small enterprise is. The main research hypothesis is: Statistical thinking is widespread in Croatian small enterprises. The research hypothesis implies that the majority of Croatian small enterprises have developed statistical thinking and that statistical methods are used in them.

The aim of the research is to test if statistical thinking is widely accepted by Croatian small enterprises. In order to make a conclusion about the named research hypothesis, an original scientific web survey in Croatian small enterprises has been conducted. The article is organized as follows. Section 2 introduces the statistical population, the survey design and analysis methods. Section 3 presents the analysis taking the complex survey design into account. Section 4 presents the conclusions of the study.

## **DATA COLLECTION AND RESEARCH METHODS**

### **STATISTICAL POPULATION**

The survey target population [37] includes active Croatian small enterprises that use statistical methods. A small enterprise is an enterprise which meets two out of three of the following criteri: the amount of total assets is lower than HRK 32 500 000,00; the amount of revenue is lower than HRK 65 000 000,00; and the average number of employees during the financial year is lower than 50 [38]. In order to be considered a Croatian enterprise an enterprise has to be registered in the Court Register of the Republic of Croatia. The research included only enterprises with the legal form of a corporation [39].

The Croatian Company Directory of the Croatian Chamber of Economy was used as a sampling frame [40]. The sampling frame contained the updated list of all registered small enterprises. On 1 October 2012, there were 87 805 small enterprises in Croatia with the legal form of a corporation. The problem was that the list included inactive enterprises as well as enterprises that on average had no employees during a year. Consequently 30 449 enterprises were excluded from the analysis and thus the target population was reduced to 57 356 small enterprises. In spite of that representative sample, because of complete sampling frame and known nonzero probabilities of selection, can be obtained [41].

### **SURVEY DESIGN**

In order to get information about enterprises' attitude towards statistical thinking, a web survey was made. Another problem was that all enterprises did not provide a valid e-mail address and because of that they were not able to participate in the survey. As a result, the sampling population consisted of 24 618 Croatian small enterprises. It is assumed that there is no statistically significant difference between enterprises that have and those that have not provided a valid e-mail address.

It is known that each enterprise's main activity area has its own special features. In order to examine if the statistical thinking position is the same in different activity areas, a complex

survey design was used and four strata were constructed based on the enterprises' main activities. In that way, an additional in-depth analysis was enabled. In order to split enterprises into four strata The National Classification of Economic Activities (NACE) was used [42]. NACE recognizes overall 21 main activity areas and indicates them with letters from A to U. The first stratum includes industrial enterprises from the activity areas B, C, D, E, and F. The second stratum consists of trade enterprises (the activity area G). The third stratum contains enterprises which are considered as service-oriented enterprises (the activity areas H, I, J, K, L, M, N, O, P, Q, S). The rest of enterprises are placed into the Other stratum. The last stratum includes enterprises the main activity of which, according to NACE, belongs into the activity areas A, R, T, or U.

Most enterprises were in the Services stratum (10 091), in the Trade (7 186) and in the Industrial (6 769) strata. The fewest enterprises were in the Other stratum (572). In order to achieve a margin of error equal to plus or minus 7%, with a confidence level of 95 % 196 eligible enterprises needed to be surveyed. Because the aim of the research is to investigate the position of statistical thinking in Croatian small enterprises it is necessary to observe only those enterprises that use statistical methods. Consequently, only such enterprises are eligible. Taking into account the assumed share of small enterprises that use statistical methods and the expected response rate, it was concluded that 21 000 small enterprises should be contacted. In order to sample enterprises from each strata, proportionate allocation and the simple random sampling method were used.

Within this survey, Croatian small enterprises are considered to be sampling and analysis units while enterprises' employees, primarily managers who represents the enterprise in which they work, are seen as reporting units. Their responses are considered enterprises' responses. They had to fill in the questionnaire that consisted of 6 different groups of questions. Each group had a different number of questions and covered a different area about the position of statistical thinking in an enterprise. The length and clarity of questions were maximally optimized to avoid misunderstandings. It was estimated that an enterprise needed at least 5 minutes and at most 15 minutes to complete the questionnaire. The computer programme used for the web survey prevented enterprises from skipping some questions or giving inappropriate answers. In that way the item nonresponse problem was avoided.

## **SURVEY RESPONSE RATE**

The survey started in October 2012 and lasted 15 weeks. During that period two reminders were sent to the enterprises. At the end, employees from 631 Croatian small enterprises took part in the survey and filled in the questionnaire for their enterprise but only 215 or 34,07 % of them use statistical methods in their business and are considered as eligible for the research. Because there were no partially completed questionnaires, the response rate was calculated as the total number of eligible enterprises responses over the total number of contacted enterprises and it is equal to 1,02 %. This response rate is known as Response Rate 1 or the minimum response rate [43]. The response rates in strata vary from 0,86 % in the Trade stratum and 0,88 % in the Industrial stratum to 1,22 % in the Services stratum and 1,23 % in the Other stratum.

## **ANALYSIS METHODS**

Different statistical methods were used in the analysis. Descriptive statistics methods were used as a base for inference. Selected statistical tests such as chi-square tests of independence and tests of proportion were used in the inferential analysis. In the analysis, only nonresponse adjustments weights were taken into account. The response adjustments weights were calculated as reciprocal to the response rate for each stratum separately.

## EMPIRICAL RESULTS AND DISCUSSION

### ATTITUDES TOWARDS REASONS FOR STATISTICAL METHODS USE IN SMALL ENTERPRISES

First of all, the enterprises that use statistical methods were additionally asked about the reasons of their application. According to literature review, there are six most influential reasons for statistical methods use. The enterprises could for each reason separately confirm that the reason had an impact on their decision to use statistical methods or they could disagree with that. Naturally, the enterprises could also answer that they did not know or they were not familiar if a certain reason was one of the reasons for the statistical methods use. Such answers were considered in the further analysis. Because of that, the total number of answers for each selected reason is different. Table 1 shows enterprises' estimated weighted population proportions for each reason. The proportions were calculated as:

$$p_{st} = \sum_{h=1}^H W_h p_{sh}, \quad (1)$$

where the weight  $W_h = N_h/N$  is the proportion of units in stratum  $h$ ,  $N_h$  is the known number of units in the population in stratum  $h$ ,  $N$  is the known total number of units in the population, and  $p_{sh} = (1/n_{sh}) \sum y_{kh}$  is the sample proportion in stratum  $h$ ,  $\sum y_k$  is the total number of units with observed characteristic  $k$  in stratum  $h$ ,  $n_{sh}$  is the number of units in the sample in the stratum  $h$ . Because only the nonresponse adjustments weights are used in the analysis, all sampled units in the stratum are given the same weights. In that way the "self-weighting" was conducted and there was no need for introducing more complexity in calculating  $p_{sh}$ .

The first three reasons in Table 1 may be considered as true reasons for statistical methods use because they are primarily oriented towards improving processes and business results. On the other hand, the last three reasons are considered as wrong reasons for statistical methods use because statistical methods are used only for administrative purposes. The majority of enterprises, 95 % of 215 enterprises that use statistical methods, use them because they facilitate the business decision-making process. Also, 90 % of enterprises agree that the statistical methods use helps them improve business results. Only 28 % of enterprises use statistical methods because their application has been a prerequisite for business certification and because their competition also uses statistical methods (30 %). These results indicate that the enterprises have recognized the true purpose of statistical methods as an additional tool for better management.

In order to make inference about all small Croatian companies that use statistical methods, the hypothesis test of estimated proportion was conducted. It was assumed for each reason for statistical methods application that more than half of the enterprises accept the reason as a reason of statistical methods application in their enterprise. So the test hypotheses are:  $H_0: p \leq 0,5$  and  $H_1: p > 0,5$ . The population sampling variance of the stratified estimator was calculated as:

$$V_{st} = \sum_{h=1}^H W_h^2 \frac{1-f_h}{n_{sh}-1} p_{sh}(1-p_{sh}), \quad (2)$$

where  $f_h = n_{sh}/N_h$ . The results of the conducted statistical tests are shown in Table 2. According to those results it can be concluded that at the significance level  $\alpha = 0,05$  the null hypothesis can be rejected for the following reasons: statistical methods facilitate the business decision-making process; the statistical methods usage improves business results; the statistical methods application leads to achieving cost efficiency. In that way, it is confirmed

that most of the enterprises have right motives for using statistical methods and that they do not use statistical methods only because of administrative reasons.

The  $\chi^2$  tests of independence between accepting the reason as a reason for statistical methods application in an enterprise, and enterprises' activity has also been conducted. In the analysis the Other stratum was omitted because of an insignificant number of such enterprises. The test results are given in Table 3. It can be concluded that at the significance level  $\alpha = 0,05$  there is no statistically significant dependence between accepting the reason as a reason for statistical methods application in an enterprise and enterprises' activity for all reasons except the reason that the statistical methods application leads to achieving cost efficiency. The reason

**Table 1.** Attitudes towards reasons for statistical methods use in small enterprises, weighted proportions,  $n = 215$ . Source: conducted survey.

Reason	The reason for stat. methods use		No. of answers
	Yes	No	
Statistical methods facilitate the business decision-making process	0,9502	0,0498	202
Statistical methods usage improves business results	0,8955	0,1045	194
Statistical methods application leads to cost efficiency	0,8718	0,1282	183
The management demands statistical methods usage	0,4360	0,5640	195
Statistical methods have been used by competitors	0,3048	0,6952	149
Statistical methods use has been a prerequisite for business certification	0,2763	0,7237	183

**Table 2.** Hypothesis tests of proportions of reasons for statistical methods application in small enterprises,  $n = 215$ . Source: conducted survey.

Reason	Sample size	Estimated proportion	Standard error	z-value	p-value
Statistical methods facilitate the business decision-making process	202	0,9502	0,0157	28,70	0,0000
Statistical methods usage improves business results	194	0,8955	0,0221	17,93	0,0000
Statistical methods application leads to achieving cost efficiency	183	0,8718	0,0233	15,95	0,0000
The management demands statistical methods usage	195	0,4360	0,0364	-1,76	0,9608
Statistical methods have been used by competitors	149	0,3048	0,0398	-4,90	1,0000
Statistical methods usage has been a prerequisite for business certification	183	0,2763	0,0340	-6,59	1,0000

**Table 3.**  $\chi^2$  tests of accepting the mentioned reason as the main reason for statistical methods application in an enterprise and enterprises' activity, without the Other stratum,  $n = 209$ . Source: conducted survey.

Reason	Sample size	df	Chi-square test statistic	p-value
Statistical methods facilitate the business decision-making process	196	2	0.512	0.7741
Statistical methods usage improves business results	188	2	0.824	0.6625
Statistical methods application leads to achieving cost efficiency	178	2	9.227	0.0099
The management demands statistical methods usage	189	2	1.062	0.5881
Statistical methods have been used by competition	144	2	4.783	0.0915
Statistical methods usage has been a prerequisite for business certification	177	2	3.093	0.2130

reason for such a conclusion is the proportion of Services enterprises that agree that the statistical methods application leads to achieving cost efficiency, which is considerably lower than the proportion of Industrial and Trade enterprises.

## **STATISTICAL METHODS POSITION IN ENTERPRISES' KEY BUSINESS CASES**

An additional proof that the enterprises have recognized the true purpose of statistical methods use is the level of their involvement in enterprises' key business cases. So, 178 enterprises or 83 % of enterprises in the sample that use statistical methods use them as a decision-making support in very important and key business cases. Out of that number, 46 enterprises always use statistical methods in such cases, and 132 enterprises do that occasionally. Only 30 enterprises or 14 % of enterprises in the sample that use statistical methods do not use them as a decision-making support in very important and key business cases. The rest of enterprises were not familiar with the fact whether statistical methods were used in their key business cases.

## **REASONS FOR LACK OF STATISTICAL METHODS APPLICATION**

Croatian small enterprises that use statistical methods have recognized the importance and the role of statistical methods. But according to survey results, only 80 enterprises or 37 % of enterprises that use statistical methods, are satisfied with the level of statistical methods use in their business. On the other hand, 112 enterprises or 52 % of enterprises that use statistical methods think that they should use more statistical methods. The employees in the rest of enterprises (11 %) could not evaluate the level of statistical methods use in their enterprise. Such enterprises are omitted from the analysis in conducting the hypothesis test of proportions on upper limit. It is assumed that the majority of Croatian small enterprises are not satisfied with the level of statistical methods use in their business. According to that, the test hypotheses are  $H_0: p \leq 0,5$  and  $H_1: p > 0,5$ . The test results suggest that, at the significance level of  $\alpha = 0,05$ , the null hypothesis may be rejected ( $n = 192$ ;  $\hat{p} = 0.5982$ ;  $se = 0.0358$ ;  $z = 2.75$ ;  $p = 0.0030$ ). Consequently, it might be concluded that statistical methods are not used enough in more than 50% of enterprises. The same conclusion can be brought for Industrial ( $n = 41$ ;  $\hat{p} = 0.6585$ ;  $se = 0.0781$ ;  $z = 2.03$ ;  $p = 0.0212$ ), and Trade enterprises ( $n = 48$ ;  $\hat{p} = 0.6667$ ;  $se = 0.0722$ ;  $z = 2.31$ ;  $p = 0.0105$ ). On the other hand, this conclusion cannot be made for Services enterprises at the significance level of  $\alpha = 0.05$  ( $n = 97$ ;  $\hat{p} = 0.5052$ ;  $se = 0.0508$ ;  $z = 0.10$ ;  $p = 0.4596$ ).

In total, six reasons for a lack of statistical methods use are identified. Enterprises that use statistical methods could agree or disagree with each of these reasons according to their impact on the level of statistical methods use in their enterprise. According to the results in Table 4

**Table 4.** Reasons for a lack of statistical methods application in small enterprises, weighted proportions,  $n = 215$ . Source: conducted survey.

<b>Reason</b>	<b>The reason for lack of stat. methods use</b>		<b>No. of answers</b>
	<b>Yes</b>	<b>No</b>	
The existing overloaded of employees with other jobs and assignments	0,7563	0,2437	200
Statistical methods are not well known in the enterprise	0,7366	0,2634	198
The lack of qualified personnel	0,5827	0,4173	193
Lack of financial resources	0,5583	0,4417	193
The nature of the product / service	0,5185	0,4815	191
The additional statistical methods application would not have an impact on business results	0,2799	0,7201	180

the most important reason for a lack of statistical methods applications is that the employees are already overloaded with the existing jobs and assignments. The second important reason is that statistical methods are not well known in the enterprises. In order to solve these two reasons and the third one, the lack of qualified personnel, an enterprise should employ one or more statisticians. In that way, a highly qualified person would perform statistical analyses and other employees would in that case have more time for other tasks. Of course, an enterprise should employ a new person only if it has enough financial resources for it.

## **STATISTICAL METHODS USE KNOWLEDGE IN SMALL ENTERPRISES**

Before any investments in additional education, the enterprise should be familiar with employees' knowledge about statistical methods application. Croatian small enterprises that uses statistical methods were asked to give an average grade for their employees' knowledge about statistical methods. Out of 182 enterprises, only 8 enterprises or 4 % gave the highest grade, grade A, to their employees for statistical methods use knowledge. Most enterprises, 70 enterprises or 38 %, gave grade C to their employees. The lowest grade, grade E, was given to employees in 19 or in 10,44 % of enterprises.

It is assumed that grades C, D and E present a non-satisfactory statistical knowledge level. In order to determine if the majority of enterprises have a non-satisfactory statistical knowledge level a statistical hypothesis test for proportion on upper limit was conducted. Consequently, the hypotheses are  $H_0: p \leq 0,5$  and  $H_1: p > 0,5$ . At the significance level  $\alpha = 0,05$  the null hypothesis can be rejected ( $n = 182$ ;  $\hat{p} = 0,7784$ ;  $se = 0,0308$ ;  $z = 9,05$ ;  $p = 0,0000$ ), which means that in over than 50% of enterprises employees do not have a satisfactory level of statistical methods application knowledge. The same conclusion can be made for Industrial ( $n = 41$ ;  $\hat{p} = 0,7805$ ;  $se = 0,0781$ ;  $z = 3,59$ ;  $p = 0,0002$ ), Trade ( $n = 45$ ;  $\hat{p} = 0,8444$ ;  $se = 0,0745$ ;  $z = 4,62$ ;  $p = 0,0000$ ) and Services ( $n = 92$ ;  $\hat{p} = 0,7174$ ;  $se = 0,0521$ ;  $z = 4,17$ ;  $p = 0,0000$ ) enterprises.

It is obvious that the enterprises should invest more into employees' education in the field of statistical methods use. But the question if they and how much they invest in their employees' education in this field remains. The conducted hypothesis test of proportion on upper limit, with hypotheses  $H_0: p \leq 0,5$  and  $H_1: p > 0,5$ , at the significance level  $\alpha = 0,05$  has shown that the majority of Croatian small enterprises do not invest in statistical methods education ( $n = 191$ ;  $\hat{p} = 0,6105$ ;  $se = 0,0357$ ;  $z = 3,09$ ;  $p = 0,0010$ ). It is remarkable that only 18 enterprises out of 191 (9,42 %) invest more than HRK 10 000,00 into statistical education yearly.

No significant progress in statistical methods knowledge in Croatian small enterprises is expected because 161 or 75 % of the sample enterprises that use statistical methods are not familiar with statistical education possibilities available on the Croatian market. It leads to the conclusion that first a lot of effort should be invested into informing enterprises about statistical education possibilities. After that it would be possible to suggest the most appropriate topics for their business. Also it has been shown that 33 or 15 % of enterprises in the sample are not satisfied with statistical methods education offer on the market. On the other hand, 21 or only 10 % of enterprises in the sample are satisfied with statistical methods education offer available on the market.

## **IMPACT OF STATISTICAL METHODS USE ON BUSINESS RESULTS**

The sample includes 56 enterprises that used statistical methods from their founding. There are 113 enterprises that started to use statistical methods at a certain point in time after the enterprise's founding. In 76 or 67 % of such enterprises business situation was better than in the time before statistical methods use. Detailed results grouped based on the main enterprise activity are shown in Table 5.

The results in Table 5 show whether the business situation in enterprises is better, the same or worse after introducing statistical methods application. But these results do not reveal either strength or the level of business results improvement. According to the results in Table 6 in 45 % of enterprises the impact of statistical methods application on the enterprises' business situation is significant. That means that there is a huge gain in business results due to statistical methods use. Significantly less gain or no significant business results improvement is present in 46 % of enterprises. Only 9 % of enterprises stated that the statistical methods use had not led to any business results improvement.

In the process of statistical methods use in enterprises the time lag for positive impacts on business results to be evident appeared to be very important. So, Croatian small enterprises were also asked about the average time needed for the impact of statistical methods use on business results to be noticeable. Detailed results are shown in Table 7.

In most enterprises the results of statistical methods applications are noticeable on average within 6 to 12 months. Overall, in the vast majority of enterprises in the sample (79 %), the statistical methods use shows its impacts on the business results in less than one year. In the rest of the observed enterprises, the statistical methods use impact is reflected on the business results in the period which is longer than one year. In those enterprises it is questionable if the statistical methods are applied in a proper way and if they are applied efficiently.

**Table 5.** Situation in small enterprises after introducing statistical methods use,  $n = 113$ . Source: conducted survey.

Activity	Situation in the enterprise						Total	
	Better		The same		Worse			
	No.	%	No.	%	No.	%	No.	%
Industrial	19	79	4	17	1	4	24	100
Trade	24	67	12	33	0	0	36	100
Services	31	62	19	38	0	0	50	100
Other	2	67	1	33	0	0	3	100
Total	<b>76</b>	<b>67</b>	<b>36</b>	<b>32</b>	<b>1</b>	<b>1</b>	<b>113</b>	<b>100</b>

**Table 6.** Statistical methods application impact on enterprises' business results improvement,  $n = 180$ . Source: conducted survey.

Activity	Level of impact						Total	
	Significant		Non significant		No impact			
	No.	%	No.	%	No.	%	No.	%
Industrial	24	56	14	33	5	12	43	100
Trade	21	45	25	53	1	2	47	100
Services	34	40	42	49	10	12	86	100
Other	2	50	2	50	0	0	4	100
Total	<b>81</b>	<b>45</b>	<b>83</b>	<b>46</b>	<b>16</b>	<b>9</b>	<b>180</b>	<b>100</b>

**Table 7.** Average time needed for the impact on business results due to statistical methods use,  $n = 149$ . Source: conducted survey.

Activity	Average time needed to have an impact on business results						Total	
	Less than 1 month	1 – 3 months	3 - 6 months	6 - 12 months	1 - 3 years	More than 3 years		
	%	%	%	%	%	%	No.	%
Industrial	5	30	14	35	16	0	37	100
Trade	0	22	17	39	17	5	41	100
Services	15	12	24	27	19	3	67	100
Other	0	0	50	0	50	0	4	100
Total	8	19	20	32	19	3	149	100

## **CONCLUSIONS**

The article presents the statistical thinking position in Croatian small enterprises. It has been shown that the vast majority of Croatian small enterprises (65,93 %) do not even use statistical methods in their business. This data do not support the main research hypothesis that statistical thinking is widespread in Croatian small enterprises. On the other hand, it has been shown that enterprises that use statistical methods have recognized the value and capabilities of statistical methods use. So, the right reasons for statistical methods use have prevailed over the administrative reasons. This goes in favor of the hypothesis that statistical thinking is developed in Croatian small enterprises. The fact that 83 % of enterprises that use statistical methods use them as a decision-making support in very important and key business cases indicated that statistical methods use has an important place in Croatian small enterprises business. However, half of the enterprises (52 %) admit that there is a lack of statistical methods use in their business. It has been shown that the two main reasons for scarce statistical methods use in small enterprises are the existing overload of employees with other jobs and assignments and the employees' insufficient statistical methods use knowledge. Another problem is that enterprises do not invest or invest almost nothing into employees' statistical methods use knowledge. The main reason for that could be the fact that three quarters of the enterprises are not familiar with statistical education possibilities in Croatia. The survey shows that in only one enterprise the situation in the enterprise has become worse than before introducing statistical methods. In only 9 % of small enterprises statistical methods use have not led to any business results improvement. In most enterprises the statistical methods use impact on business results is noticeable on average in the period from 6 to 12 months from the time their introduction.

The conducted research has shown that statistical thinking is not widespread in Croatian small enterprises. Despite this, it can be concluded that statistical thinking has a very important position and role in enterprises that use statistical methods in their business. Naturally there is a lot of space for improvement. More efforts should be invested into introducing statistical methods use features and benefits to enterprises that do not use them. The future research should investigate the reasons why some enterprises do not use statistical methods. In order to get a better insight into statistical methods use in enterprises, the future research should be able to answer questions about the commonly used statistical methods in enterprises, as well as frequency and quality of their use. The answers to these questions will provide the ground for further improvement and better affirmation of statistical methods in enterprises. All these efforts should lead to even better business results. The main limitation of this research is that it only observes Croatian small enterprises. Future research should also observe medium-sized and large enterprises.

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## ANKETNO ISTRAŽIVANJE O PRIHVAĆENOSTI STATISTIČKOG NAČINA RAZMIŠLJANJA I METODA U HRVATSKIM MALIM PODUZEĆIMA

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### SAŽETAK

Predmet istraživanja rada jest ispitati stav menadžera u hrvatskim malim poduzećima koja primjenjuju statističke metode prema statističkom načinu razmišljanja kako bi se bolje upoznala problematika povezana s tim područjem. Istraživanje je provedeno 2013. godine primjenom web ankete na slučajnom uzorku od 631 malog hrvatskog poduzeća. kako bi se dobile što detaljnije informacije korišten je složen istraživački dizajn uzorka. U analizi su korišteni hi-kvadrat testovi neovisnosti i statistički testovi proporcija u kojima su proporcije bile vagane temeljem faktora neodgovora. Pokazalo se da većina hrvatskih malih poduzeća (65,93%) ne koristi statističke metode u svojem poslovanju. S druge strane, poduzeća koja primjenjuju statističke metode prepoznala su njihovu važnost i mogućnosti. Istraživanjem je utvrđeno da većina poduzeća ne primjenjuje statističke metode zbog administratorskih razloga. Premda koriste statističke metode kao podršku u procesu donošenja poslovnih odluka u veoma važnim i ključnim poslovnim slučajevima, hrvatska mala poduzeća priznaju da je razina primjene statističkih metoda u njihovom poslovanju na nezadovoljavajućoj razini. Također, investicije u primjenu statističkih metoda su veoma oskudna. Navedeno je dovelo do spoznaje o niskoj razini znanja zaposlenika iz područja primjene statističkih metoda. Primjena statističkih metoda dovila je do boljih poslovnih rezultata u više od 90 % malih poduzeća. Rezultati primjene statističkih metoda se prepoznaju u rezultatima poslovanja u prosjeku s odmakom od 6 do 12 mjeseci. Istraživanjem je zaključeno da bi se trebalo više ulagati u razvoj statističkog načina razmišljanja u poduzećima s ciljem povećanja primjene statističkih metoda te unapređenja rezultata poslovanja.

### KLJUČNE RIJEČI

statističko razmišljanje, istraživanje u poduzećima, složeni istraživački dizajn uzorka, vagani stratificirani procjenitelj proporcije, hi-kvadrat testovi neovisnosti

# WHO CREATES THE TIME: NATURE OR HUMAN?

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## ABSTRACT

The aim of this article is to defend the thesis that analysis of time meaning within history and philosophy of natural sciences and philosophical anthropology allows making clear the basis of human being. It's opened the opportunity of constructing special model of general understanding of time as a creation of nature or as a creation of human. Two main methods are used: comparative analysis and hermeneutics.

Article presents the discussion of following results. Orientation on discretization and virtual nature of cultural interaction, or orientation on mutual tension of limits of cultural and historical process allows connecting philosophy of natural sciences and philosophical anthropology with system of physical categories: energy, weight, distance, etc. It finds an application as in the physical and mathematical sphere so in the field of humanistic studies. The general conclusion made is that neither nature nor human solely creates the time. Time is an imaginary phenomenon connecting human activity and natural processes in the limits of human consciousness.

## KEY WORDS

time ontology, meaning of time in physical and mathematical science, meaning of time in philosophical anthropology, creator of time

## CLASSIFICATION

APA: 2340, 2630, 4010

JEL: O30

PACS: 04.90.+e

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## INTRODUCTION

### BACKGROUND

An article is clearing up the ratio of meanings of time in a context of philosophy of physical and mathematical natural science and philosophical anthropology. Relevance of the matter is caused at least from two parties. Firstly, cultural development of scientific knowledge assumes philosophical justification [1; pp.259-260]. According to Kant, time concept is the cornerstone of mathematical knowledge and because of that it allows developing conditions of possibility of understanding of physical processes [2; pp.84-88]. Therefore the analysis of understanding of time opens the specific direction of philosophical justification of physical and mathematical natural science. Secondly, the time concept sends not only to area of natural processes but also their sense concerning a being perspective in general and questions of human being in particular [3; p.27, 3; p.451]. Therefore the analysis of time meaning allows clearing up the basis of human being and constructing special model of its philosophical and anthropological understanding.

### APPROACHES AND METHODS

The analysis of question of time meaning as relation “Nature vs. Human” allows to reveal specifics of philosophy, natural sciences and anthropology in structure of ontological knowledge as itself. It is revealed ways of creation of the general theory of nature development and also human interaction. Thereby, we can answer the question is whether nature or human creates the time.

During research were applied methods of the comparative analysis and a hermeneutics. These methods allow comparing the features of interpretation of time within fundamentals of physical and mathematical natural sciences and philosophical anthropology. So, it could be constructed the general model of interpretation.

### CLASSICAL POSITION: NATURE “CREATES” THE TIME

There are two most important positions in the history of time ontology: classical natural philosophical approach (Aristotle, Hegel, etc.) and accenting on human being approach (Husserl, Heidegger, etc.). Bulks of modern theories, both in physical and mathematical natural sciences, and within humanitarian thought are in fact continuation of these directions. For example unlike traditional views in the theory of strings total more than three dimensions of space-time continuum. However, in its basis the theory of strings is a kind of natural philosophy. In a counterbalance to it modern historical issues (for example by H. White) are in many respects obliged to philosophical and anthropological ideas of the first half of the XXth century.

Aristotle analyzes time in categories of existence and nonexistence as natural (physical) phenomena [4; pp.145-156]. As starting position fixing of essentially problematical nature of disclosure of the nature of time acts [4; p.145]. The analysis of traditional for its era concepts leads Aristotle to a number of the important conclusions. Firstly, time is not movement. It cannot “move” (in itself) regarding some necessary way of measurement of mobility for it, but such way coincides with time and it conducts to need of time interpretation through concepts of immovability and invariance [4; p.147]. Secondly, time also has to possess variability and mobility signs [4; p.147]. Therefore time possesses both immovability signs and lines of mobility. Time in itself cannot be divided but in the same relation has to be subdivided into separate parts. The nature of time is inconsistent and demands the special

understanding allowing eliminating the revealed contradiction. In this regard Aristotle believes that time is a measure of the movement expressed in the numerical relation to any possible movement and change [4; pp.149-150]. It is issued the understanding of time as the paradoxical phenomenon acting both as complete image and internally divided phenomenon. The paradox of time demands representation it as the formation similar to points of mathematical lines. It is expressed that division of time is applied in cases of ensuring understanding of the message on some event [4; p.155]. Thus, time is inconsistent (uniform and multiple) forming is in itself motionless and invariable and acts as numerical expression of occurring movements and changes, and time also appears in the form of a complex of pragmatic rules of ordinary language practice. All this testifies Aristotle understands time in a relative separation from real processes in the material nature, pulls together it with area of human relationship and gives the grounds to identify it with epiphenomenon of public life.

Special interpretation of time within history and philosophy of natural sciences is represented by Hegel. Hegel correlates time to space including it in process of dialectic formation of Absolute Spirit at an embodiment stage as initially Absolute Idea within an alter-being of this Idea ordering of one of the parties of a material world [5; p.51]. Thus, the general understanding of time coincides with two moments: 1) contradiction to space; 2) the discretization forming in total of points of gap independent images namely the line and a surface (i.e. the plane).

Hegel reproduces Aristotle's idea of rather paradoxical character of the nature of time, but Hegelian position only in a form coincides with the point of view of Aristotle [5; p.52]. Time reveals in categories of existence and nonexistence as internally inconsistent phenomenon, by permission of this contradiction the direction opposite to the Aristotelian line of thought acts. Hegel believes that time in itself coincides with physical process (duration) and puts forward the thesis about limited character of its paradoxicality, abnegation of this paradoxicality at higher steps of development of the nature [5; pp.54-55]. Time is a pure form of the organization of representation of natural processes. In this regard processes are constituted by the moments of distinction which reveals as infinite division and uniform reproduction of reference points of change of an ontological situation. Being is represented within the concepts sending to possibility of some number of positions and states (past, present or future) and reveals as correlated to a necessary scale of transitions between these positions and states. The scale possesses inconsistent properties and cannot be understood with accuracy as cash actually or absent in it. It is connected with Hegelian interpretation of time in itself as "being disappearances in nothing and nothing in being" [5; p.56].

On the basis of the analysis of classical approaches to representation of time it is possible to draw some general conclusions. Firstly, the nature of time has internally inconsistent (paradoxical) character and consists in unity of its existence and nonexistence. Secondly, time is identified with imaginary movement in the Greek classics and also ideal (formal) process of formation of the nature in the German classical thought. Thirdly, the general understanding of time is connected with its "mathematic" character, i.e. formality and universalistic meaning as regulation of language practice, according to Aristotle, and also the organization of quantitative parameters of intelligence of natural processes, according to Hegel.

These conclusions allow correlating natural philosophical interpretation of time to its philosophical and anthropological understanding. The foundation is laid by Heidegger who developed Husserl's ideas in a context to consecutive criticism of bases of science in Modern Times. Husserl in his criticism came to idea of replacement in physical and mathematical natural sciences of a direct reality of the sensual world a complex of geometrical methods of

idealization of the phenomena of the material nature [6; pp.8-9]. Heidegger developed that researches and opened special understanding of time.

## **NON-CLASSICAL POSITION: HUMAN EXISTENCE AS THE “CREATOR” OF TIME**

### **PHILOSOPHICAL POINT OF VIEW**

According to Heidegger, basis of conceptualization of time is the existential analytics of presence, i.e. being of human in the world and also conditionality of scientific knowledge (about the human, society and nature) as basic intentions of its existence [3; p.29]. According to Heidegger, the nature of time coincides with two versions of interpretation: “ordinary” which sense corresponds to irreflexively accepted assumption of identity of time and direct fixing of course of natural processes [3; p.475] and also the “ecstatic and horizon” interpretation meaning a reflection of the intention of an ordinary understanding of time in the form of irreversible alternation of the moments of change of states within surrounding reality. The second interpretation assumes that daily intention sets a way of understanding of the world and Heidegger considers that time nature in principle corresponds to this ability of the human to be present, be in the world, in a literal word meaning proceeding from itself [3; p.475].

Thus, the classical understanding of time and modern interpretation correspond, firstly, as intention on correlation allocation between natural processes and the sphere of their knowledge, and, secondly, as the form of intension on time restriction with area of human being. Aristotle and Hegel reveal a paradoxicality, the general formality and universality of time regulating (to all appearances and through a prism of language norms, according to Aristotle, and also it is ideal, according to Hegel) natural processes. Heidegger opens irreflexivity of this concept at all and believes that time belongs only to the sphere of being of the human in the world, but not to world being as itself.

It is easy to see that the philosophical and anthropological concept complicates exact compliance of time of area of natural sciences. In a necessary way time cannot be included in all completeness of own sense in a framework of the valid process of natural-science research. The reality of such process has to be called into question in borders of actual understanding of time. But we can show the way to solve this problem.

### **INTERDISCIPLINARY POINT OF VIEW: PHILOSOPHY OF TIME WITHIN PHYSICS?**

We take the principled stand that there are some fundamental prerequisites in following relations:

- (1) idea of discretization of cultural and historical process;
- (2) virtual nature of interaction of consciousness limits in philosophical and scientific knowledge (elements of limitation are found in real history and are in the oppositional relation to last and (or) hypothetically possible future moments) [7; pp.11-44].

Our position sends to a complex of philosophical provisions but also can be formulated in natural-science categories of a time point as  $t$ , energy as  $E$ ,  $m$  as body mass, and also distances as  $r$  (enter the classical theory of gravity (Newton) and relativistic mechanics (Einstein)). There is possible a special interpretation of time. Time connects action of the phenomenon or its *energy* with some kind of *weight*, the historical importance of a separate limit of consciousness through distance analogue as intensity of cultural and historical space, i.e. oppositional nature of interaction of intentions.

So, the complex of philosophical and physics ideas which allow finding a way of rational justification of natural sciences comes to light coordinating philosophical and anthropological understanding of a ratio of time and being, and also elements of physical science.

## **CONCLUSION**

Evolution of representations results of time meaning within history and philosophy of natural sciences (esp. within history and philosophy of physics) leads to the problematical correlation of time to natural processes. The meaning of time assumes its paradoxical, ideal and universal character; reality and time correspond only to the world of phenomena of human existence.

We have found one of the ways of solving this problem. Orientation on the rules of discretization and virtual nature of interaction, or orientation on mutual tension of limits of cultural and historical process allow connecting philosophy with system of physical categories (energy, weight and others), which find application as in the physical and mathematical sphere so in the field of humanitarian researches.

Thus one can conclude that neither nature nor human create the time. Time is an imaginary phenomenon connecting human activity and natural processes in the limits of human consciousness.

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## **TKO STVARA VRIJEME: PRIRODA ILI ČOVJEK?**

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### **SAŽETAK**

Rad obrazlaže tezu kako analiza značenja vremena u povijesti i filozofiji prirodnih znanosti te u filozofskoj antropologiji razjašnjava temelj ljudskog življenja. To otvara mogućnost konstruiranja posebnih modela općeg razumijevanja vremena kao tvorevine prirode ili kao ljudske tvorevine. U radu se koriste dvije metode: komparativna analiza i hermeneutika.

U radu je razmotreno sljedeće: orijentiranje na diskretizaciju i virtualnu prirodu kulturnih međudjelovanja, orijentiranje na uzajamno rastezanje granica kulturnih i povjesnih procesa koji su omogućili povezivanje filozofije prirodnih znanosti i filozofske antropologije sa sustavom fizičkih veličina poput energije, mase, udaljenosti itd. Nađene su primjene u područjima fizike, matematike i humanističkom području. Opći je zaključak kako ni priroda niti čovjek zasebno ne stvaraju vrijeme. Vrijeme je imaginarna pojava koja povezuje ljudsku aktivnost i prirodne procese na granici ljudske svijesti.

### **KLJUČNE RIJEČI**

ontologija vremena, značenje vremena u prirodoslovju i matematici, značenje vremena u filozofskoj antropologiji, stvoritelj vremena

# CURRENT STATUS OF THE MAGNETOPLASMA COMPRESSOR DEVICE IN BELGRADE – STUDY OF PLASMA FACING MATERIALS IMPORTANT FOR FUSION REACTORS

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## ABSTRACT

The magnetoplasma compressor, a quasi stationary plasma accelerator, is a source of supersonic compression plasma flow. High plasma parameters of compression flow, large flow velocity and discharge duration enable their efficient usage for development of new plasma technologies, including material surface modification, creation of sub microstructures and nanostructures. In this paper spatial and temporal distribution of emissivity was studied using inverse Abel transform. This has been realized in LabVIEW environment. The plasma flow generated by quasi stationary plasma accelerators can be used for simulation of high energy plasma interaction with different materials of interest for fusion experiments. Surface phenomena are results of specific conditions during plasma flow interaction with target surface. As the next step in our research, spectral analysis of the plasma area around targets surface, after interaction between target and plasma, generated by magnetoplasma compressor, is planned. The first material which will be subjected to interaction with plasma will be a carbon fiber – material of big importance for divertor region in fusion devices.

## KEY WORDS

magnetoplasma compressor, Abel inversion spectroscopy, materials of interest for fusion devices

## CLASSIFICATION

JEL: Z19

PACS: 28.52.-s, 52.65.-y

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## INTRODUCTION

The magnetoplasma compressor is a source of supersonic compression plasma flow (CPF) [1-4]. It represents a magnetoplasma analog of a Laval nozzle. This is a quasi stationary plasma accelerator with semitransparent electrode system which operates in an ion current transfer regime [3].

There are few advantages of the MPC as compared with the other types of accelerators: high stability of CPF generation, controllability of discharge composition (different gases and their mixtures), size (up to 6 cm in length and 1 cm in diameter) and plasma parameters (electron density up to  $4 \cdot 10^{23} \text{ m}^{-3}$  and temperature up to 20 000 K), as well as the discharge time duration sufficient for practical applications (up to 80  $\mu\text{s}$ ) [4]. It was found that CPF parameters predominantly depend on discharge current. The plasma parameters ‘follow’ the discharge current time evolution. This dependence is a measure of plasma flow stationarity [4]. High plasma parameters of compression flows (electron density and temperature close to  $10^{23} \text{ m}^{-3}$  and 20 000 K, respectively) together with large flow velocity (close to  $100 \text{ km s}^{-1}$  in hydrogen and  $40 \text{ km s}^{-1}$  in nitrogen) and discharge duration (stable CPF close to 50  $\mu\text{s}$ ) enable their efficient usage for development of new plasma technologies, including material surface modification [5, 6], creation of sub microstructures and nanostructures, etc. MPC is of great importance for the study of fundamental processes in plasma flows and their behavior in different configurations of electric and magnetic fields. Such systems and their plasma flows are also successfully used in different plasma technologies.

Plasma interaction with materials is important for fusion investigations. In fusion devices, the first wall and divertor plasma-facing components (PFC) must provide adequate protection of in-vessel structures, sufficient heat exhaust capability and be compatible with the requirements of plasma purity [6]. ITER will combine long pulse, high power operation with severe restrictions on permitted core impurity concentrations and, in addition, it will produce transient energy loads on a scale unattainable in today’s devices. Intense thermal loads in ITER and other fusion devices which occur during ELMs (edge localized modes), plasma disruptions and VDEs (vertical displacement events), will result in macroscopic erosion associated with the formation of cracks, melting, droplets, evaporation or sublimation [7]. The main goals of plasma surface interaction investigation are simulation the expected ELM and disruption loads in ITER and other fusion devices. The plasma flow generated by quasi stationary plasma accelerators can be used for simulation of high energy plasma interaction with different materials of interest for fusion experiments.

Generally, our research program is devoted to the construction of two stage quasi-stationary high current plasma accelerator (QHPA), a combination of four MPC – compact geometry units [3]. QHPA will be used to produce fully ionized plasma at the entrance of the acceleration channel of QHPA. Such systems are the new generation quasi-stationary plasma accelerators. These accelerators are sources of quasi stationary compression plasma flows in which the duration of the compression stable state is much longer ( $\sim 100\text{-}1000 \mu\text{s}$ ) than the flight time of the plasma in the acceleration channel of the one MPC-CG accelerator ( $1\text{-}5 \mu\text{s}$ ).

This article contains an overview of the research activity on the Belgrade MPC device, some of our new experimental data as well as plans for future steps.

## EXPERIMENTAL SETUP

The electrode system of the MPC [3] (shown in Figure 1) consists of a conically shaped copper central electrode (cathode) with radius 3 and 0,6 cm, length of 5 cm and with a divertor on

the top. A cylindrical outer electrode (anode) is made of eight copper rods (0,8 cm in diameter and 14 cm in length), symmetrically positioned along the circle of 5 cm in diameter. A conically shaped cathode of the MPC defines a profile of the acceleration channel. The discharge device of the MPC-CG is situated in a  $30 \times 30 \times 150$  cm<sup>-3</sup> vacuum chamber.

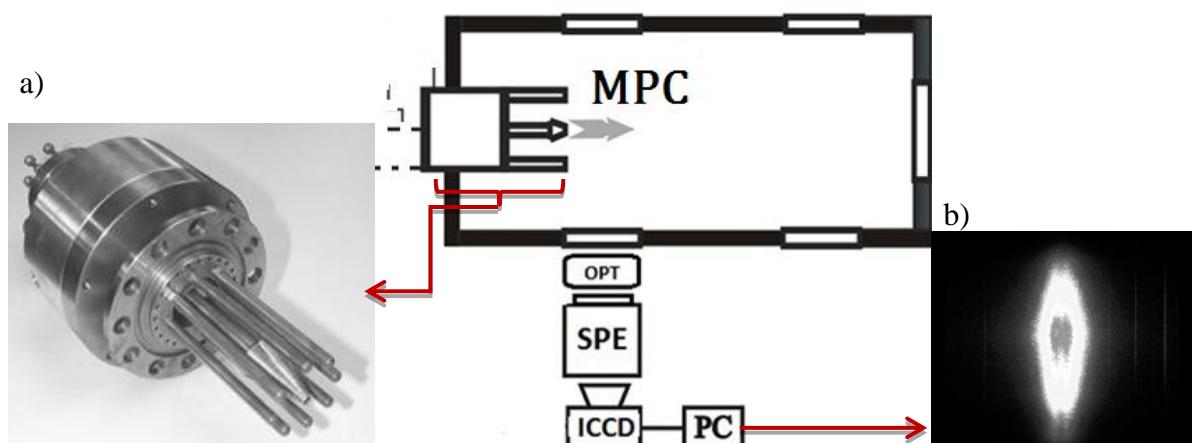
It has been found that the current cutoff, which limits the increase in the parameters in the case of classical plasma accelerators operating in the electron current transfer, can be avoided by switching to the ion current transfer [1]. Ion-drift acceleration of the magnetized plasma is realized using specially shaped accelerating channel [1]. The reduction of erosion of the electrodes is important task and because of that cathode of the MPC should not only be specially shaped, but also made of rods to be shielded by the self-magnetic field and therefore protected from the erosion.

Experimental setup consist of vacuum chamber within the MPC is positioned, optical system, Minutemen spectrometer, ICCD camera and PC, as well as of systems for voltage and current measurement. The most important part of experimental setup is schematically shown in Figure 1.

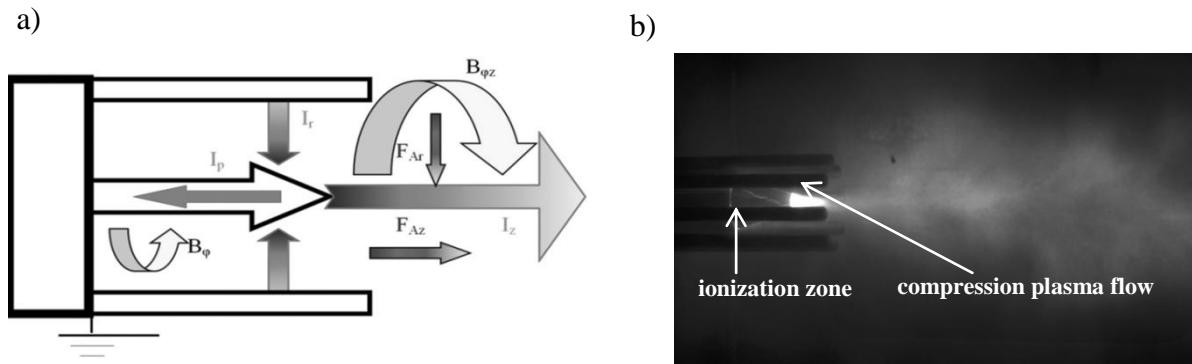
In the inter-electrode region the plasma is accelerated due to the Ampere force  $F_{Az}$ . Plasma flow is compressed due to the interaction between the longitudinal component of current  $I_z$  swept away from the discharge device, and the intrinsic azimuthal magnetic field  $B_{\phi z}$  as well as due to the dynamic pressure of the plasma flow converging to the system axis  $F_{Ar}$ . This is shown in Figure 2a.

There are four phases of the discharge development. In the first phase discharge breakdown takes place and plasma is accelerated along the cathode conical part. Second phase consist of radial plasma compression and relaxation of the accompanied plasma flow oscillations. Third phase is quasi-stationary state of compression plasma flow and in fourth part the compression plasma flow is in decay which is followed by after-glow effects. These four phases are shown in Figure 2b.

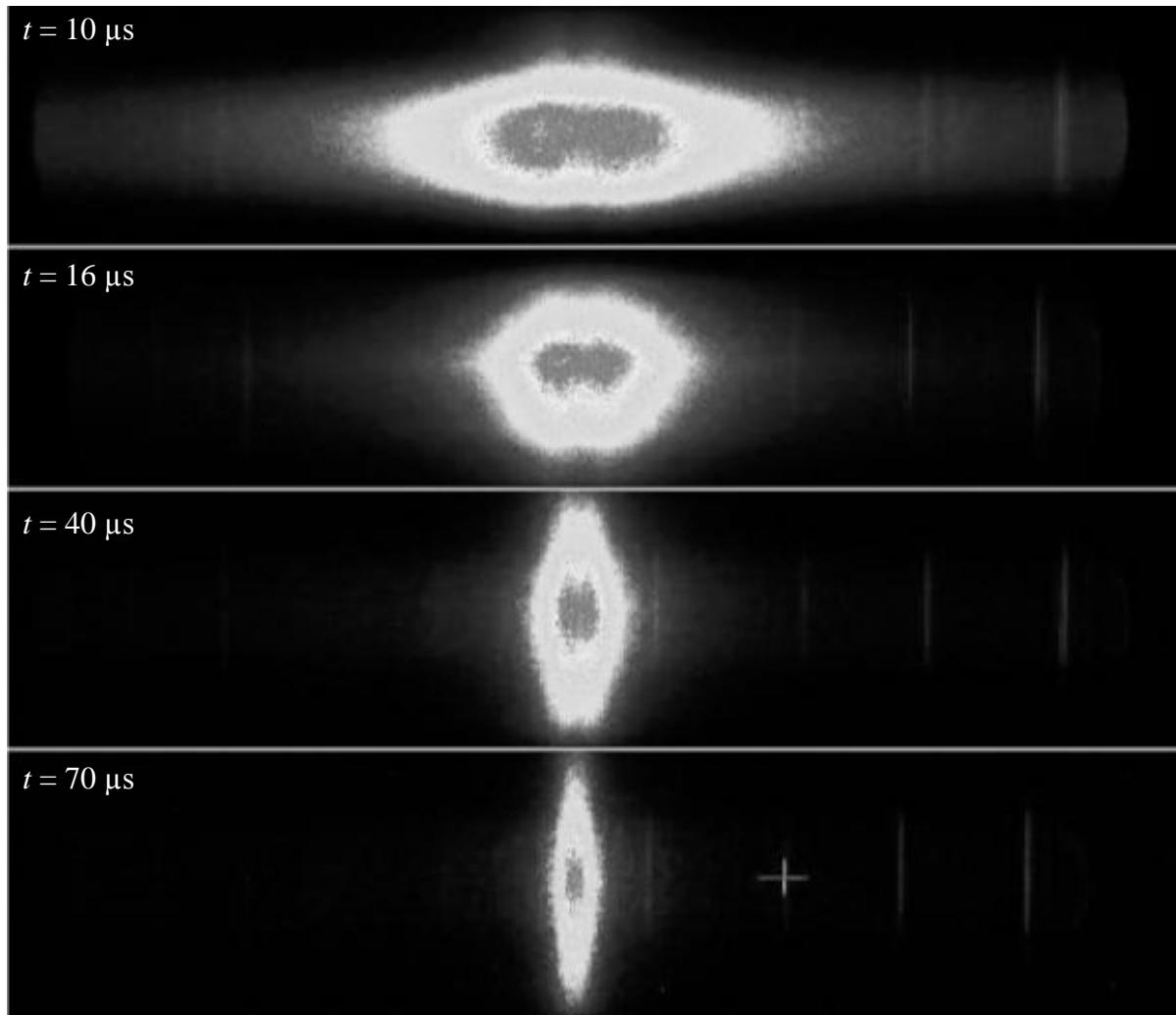
Figure 3 shows a part of time evaluation of discharge. These images have been made by using ICCD camera as detector and SpectraSuite software. SpectraSuite is a spectroscopy software program which can be used to capture and analyse spectral data from light sources with the use of a spectrometer. The width of spectral line is largest at the beginning of discharge ( $\sim 10\text{-}20$   $\mu\text{s}$ ) and after that the line width is narrower.



**Figure 1.** Experimental setup: OPT – optical system, SPE – Minutemen spectrometer, a) magnetoplasma compressor of compact geometry, b) image of plasma on a computer.



**Figure 2.** a) compression of plasma flow, b) image of plasma flow photographed with camera using the violet filter.



**Figure 3.**  $H_\beta$  (486,1 nm) recorded by ICCD camera, shown in SpectraSuit program.

## RECENT EXPERIMENTAL RESULTS

Several papers were devoted to the study of different MPC characteristics. The electric and thermodynamic parameters of the discharge and the plasma flow created in different gases and their mixtures (hydrogen, nitrogen, argon and Ar with 3 % of  $H_2$ ) have been measured to optimize the working conditions within the 100-3000 Pa pressure range for input energy up to 6,4 kJ [3, 4, 7].

Recent research activities are related with possibility of MPC usage for investigation of high energy plasma interaction with different materials of interest for fusion experiments.

## RADIAL DISTRIBUTION OF EMISIVITY

During experimental determination of radial distribution of emissivity, working gas was hydrogen (100 %) at pressure  $p = 10$  mbar and temperature  $T \approx 40\,000$  K.

According to well-known correlation between local emissivity and measured intensity,

$$\varepsilon(r) = -\frac{1}{\pi} \int_r^R \frac{dI(y)}{dy} \frac{dy}{\sqrt{y^2 - r^2}}, \quad (1)$$

radiation profile can be found at any position along the radius of plasma if inverse Abel transformation is done. This was performed using a LabVIEW program for determining confidence intervals of Abel-inverted radial emission profiles [8]. This program works with random noise generation. One additional program has been written for data organizing and processing.

For finally analysing of data it is important to know from which point of y-axis the radiation comes. Because of that, it was necessary to calibrate the system. That has been done by using a small source of radiation: PEN-light which is Hg source, heights  $h = 3,8$  cm and  $\lambda = 435$  nm as line of interests (Figure 4).

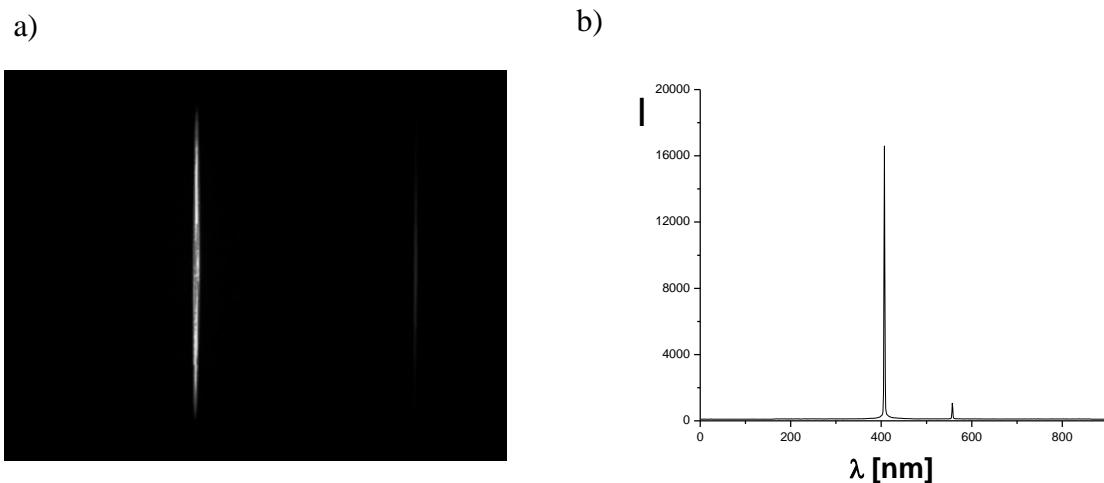
Value of one pixel in nm can be found by:

$$n = \frac{3.8 \text{ cm (y axis)}}{190 \text{ piksel}} = 0.02 \frac{\text{cm (y axis)}}{\text{piksel}} \quad (2)$$

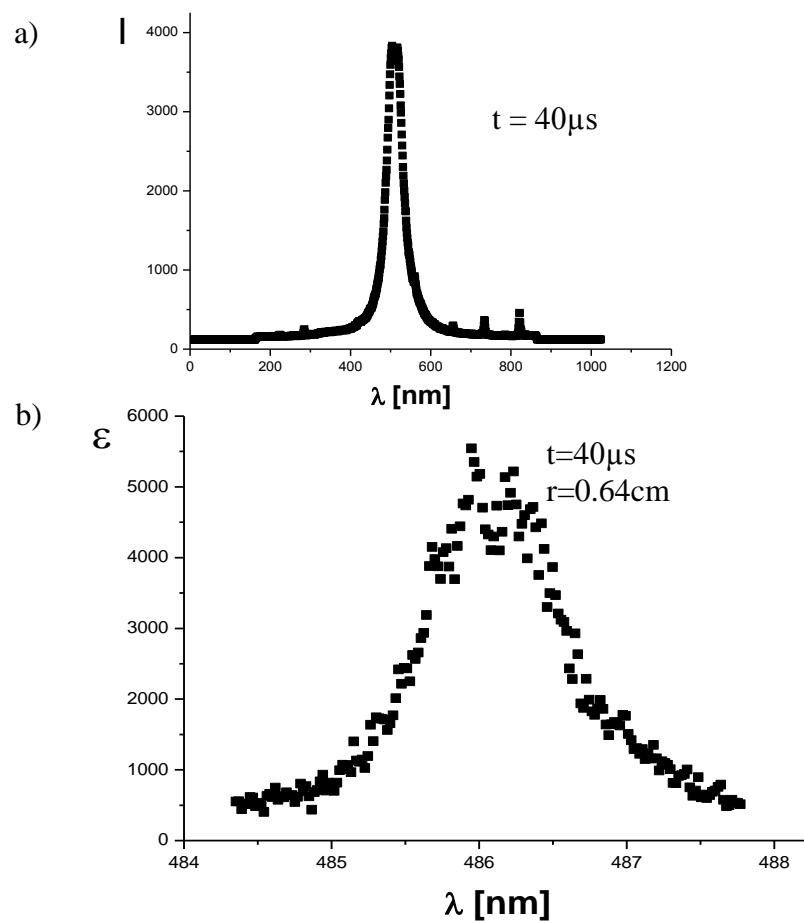
Figure 5 shows integral profile and radiation profile at one selected position along the radius of plasma.

Time evolution of emissivity at one chosen position is shown in Figure 6.

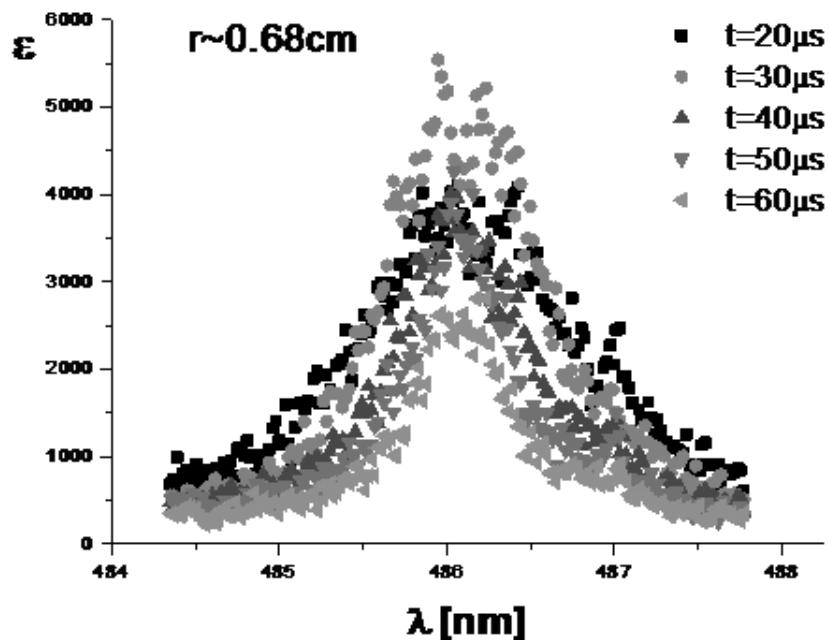
These radiation profiles have been used for determination of spatial and temporal distribution of electron concentration. One of the obtained profiles, electron concentration dependence on radius at  $t = 30 \mu\text{s}$ , is shown in Figure 7.



**Figure 4.** PEN – light, Hg I, 435 nm, ICCD camera, a. integral profile - picture from program SpectraSuits, b. Integral profile – after data processing in Origin.



**Figure 5.**  $H_{\beta}$  ICCD,  $t = 50 \mu s$ , a) integral profile, b) radiation profile at one selected position along the radius of plasma  $r = 1.43 \text{ cm}$ .



**Figure 6.** Radiation profiles at one position along the radius of plasma at different times.

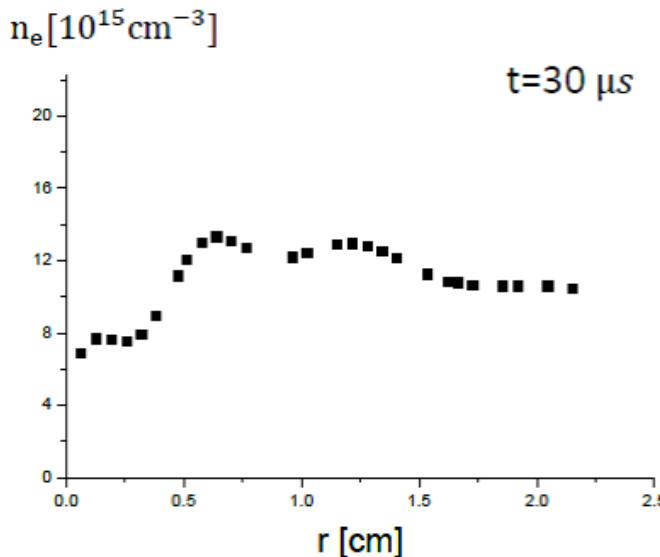


Figure 7. Electron concentration dependence on radius at  $t = 30 \mu\text{s}$ .

## PLASMA FLOW INTERACTION WITH ITER DIVERTOR RELATED SURFACES

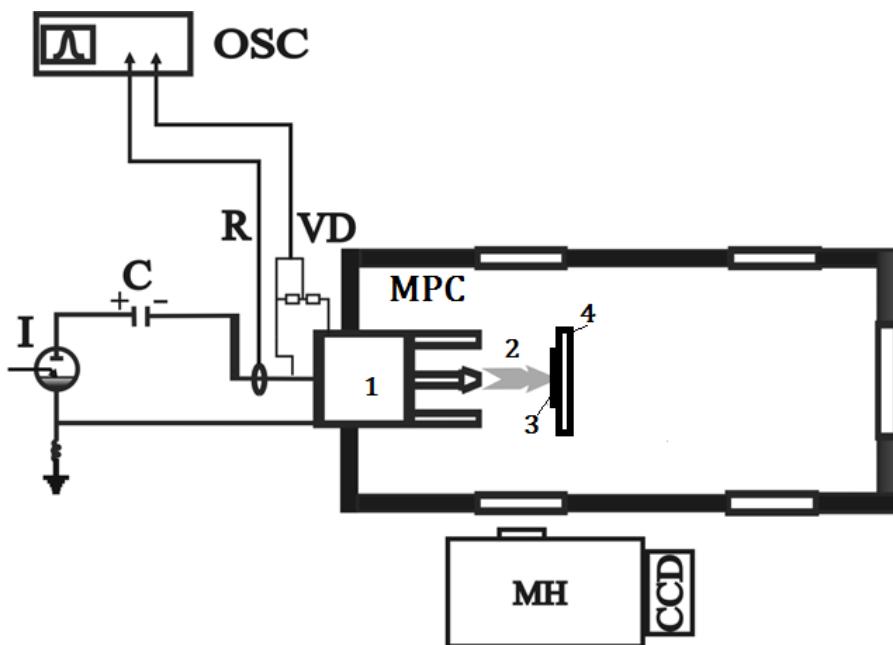
As it has been mentioned in the Introduction, the plasma flow generated by MPC can be used for simulation of high energy plasma interaction with different materials of interest for fusion experiments. Processes such as ELMs (edge localized modes), plasma disruptions and VDEs (vertical displacement events) can be studied and analysed through experiments using plasma guns. Modification of different targets, like tungsten, molybdenum, carbon fiber components (CFC) and silicon single crystal surface by the action of hydrogen and nitrogen quasi stationary compression plasma flow (CPF) generated by MPC has been studied [7]. MPC plasma flow with standard parameters (1 MJ/m<sup>2</sup> in 0.1 ms) was used for simulation of transient peak thermal loads during Type I ELMs and disruptions. Analysis of the targets erosion, brittle destruction, melting processes, and dust formation has been performed [8].

The next step is spectral analysis of the plasma area around targets surfaces generated by MPC. After the interaction between MPC plasma flow and target, phenomena as a targets erosion, destruction, melting and dust formation can be observed. Surface phenomena are results of specific conditions during plasma flow interaction with target surface. The idea is to completely analyse processes in plasma around target after interaction with plasma as it has been done in [9], but with different device (MPC) and under different conditions (source voltage, temperature, pressure). This will be a spectral analysing. The first material which will be subjected to interaction with plasma will be a carbon fiber. This type of materials, according to newest agreement, is of big importance for divertor region in fusion devices. Experimental setup is schematically shown in Figure 8.

Data analysing will include analysing of radial distribution of emissivity and spatial and temporal distribution of electron concentration. Procedure for reaching these distributions is explained in previous section.

## CONCLUSIONS

Current researches on MPC device in Belgrade are related to the fundamental aspects of high energy plasma flow interaction with materials of interest for fusion. One of the purposes is investigation of plasma interaction with first wall and divertor component materials related to



**Figure 8.** Scheme of experimental setup: (1) Magnetoplasma compressor (MPC), source of quasistationary compression plasma flow, (2) compression plasma flow, (3) sample, (4) sample brass holder.

the ITER experiment. The performance of fusion devices and of a future fusion power plant critically depends on the plasma facing materials and components. Resistances to local heat and particle loads, thermo-mechanical properties, as well as the response to neutron damage of the selected materials are critical parameters which need to be understood and tailored from atomistic to component levels. Plasma flow generated by MPC is used for investigation of high energy plasma interaction with different materials of interest for fusion experiments and every result is useful for a more complete picture of the plasma facing materials problem in fusion reactors.

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## **SADAŠNJE STANJE KOMPRESORA MAGNETOPLAZME U BEOGRADU – PROUČAVANJE MATERIJALA U KONTAKTU S PLAZMOM, BITNIH ZA FUZIJSKE REAKTORE**

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### **SAŽETAK**

Kompresor magnetoplazme, kvazistacionarni akcelerator plazme, izvor je toka plazme nadzvučne brzine. Relativno visoki parametri kompresijskog toka, znatne brzine toka i znatna trajanja izboja omogućuju njegovo učinkovito korištenje za razvoj novih tehnologija plazme, uključujući i razvoj površinskih modifikacija materijala, stvaranja submikroskopske- i nano-strukture. U ovom radu razmatrana je prostorna i vremenska distribucija emisivnosti pomoću inverzne Abelove transformacije. To je ostvareno programskim okruženjem LabVIEW. Tok plazme generiran kvazistacionarnim akceleratorom plazme može se koristiti za simulaciju visokoenergetskog međudjelovanja plazme i različitih materijala bitnih za fuzijske eksperimente. Površinske pojave rezultat su posebnih uvjeta tijekom međudjelovanja toka plazme i površine mete. Kao sljedeći korak u istraživanjima, planirana je spektralna analiza područja plazme oko površine mete, nakon međudjelovanja između mete i plazme. Prvi materijal podvrgnut međudjelovanju s plazmom bit će ugljična vlakna, materijal značajan za divertore fuzijskih reaktora.

### **KLJUČNE RIJEČI**

kompresor magnetoplazme, Abelova inverzna spektroskopija, materijali fuzijskih reaktora



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