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Faculty of Mechanical Engineering  
and Naval Architecture



SVEUČILIŠTE U ZAGREBU  
METALURŠKI FAKULTET  
UNIVERSITY OF ZAGREB  
FACULTY OF METALLURGY



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PhD Study of Mechanical Engineering, Naval  
Architecture, Aeronautical Engineering and  
Metallurgical Engineering

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## Preface

This booklet contains abstracts presented at the 3rd Annual PhD Workshop held at University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, on June 30, 2017. Annual PhD workshop is the integral part of PhD programme of Mechanical Engineering, Naval Architecture, Aeronautical Engineering and Metallurgical Engineering, launched on academic year 2014/15. PhD program is jointly developed by two faculties of University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture and Faculty of Metallurgy.

PhD workshop is aimed to provide forum for exchange of ideas among PhD students, to get most of PhD students at one place and to monitor progress of their PhD theses. Workshop should help students to strengthen their presentation skills and unify quality and transparency of PhD theses produced at different modules of PhD programme. Contributions in this booklet are divided in two broad groups, abstracts of preliminary PhD topics and abstracts of final PhD topics. Former are mostly presented by the first year PhD candidates, while latter are presented by PhD students of second and higher years. Abstract are structured in a way to encourage students to write clearly and concisely purposes of their PhD theses in order to bring their research closer to the wide community and even to those who are not specialists in the field. This booklet could be a valuable and relevant reference for PhD students and their mentors as it represents kind of milestone in the progress of their PhDs. It will also be useful for all stakeholders of PhD education to evaluate quality and progress of PhD theses. Finally, it can be useful for the industry in Croatia as it contains in one place most of the research efforts at two faculties.

31 participants on the PhD workshop presented preliminary topics of their theses, while 29 participants presented final PhD topics. Contributions collected in the booklet of abstracts are from different modules of the PhD study: Process and Energy Engineering (24 contributions), Theory of Structures (8), Industrial Engineering and Management (7), Computational Mechanics (6), Materials Engineering (4), Naval Architecture and Ocean Engineering (3), Scientific Metrology in Mechanical Engineering (2), Advanced Production Technologies (2), Metallurgical Engineering (2), Mechatronics and Robotics (1) and Aeronautical Engineering (1). Diversity of these topics clearly indicates broad and rich research interests and activities at the Faculty of Mechanical Engineering and Naval Architecture and Faculty of Metallurgy.

*Editors*



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## **PRELIMINARY PHD TOPICS**





# Self-Healing Microcapsule Based Coating for Corrosion Protection of Offshore Wind Farms

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**Mentor/s:** Ivan Stojanović

**Affiliation:** Energy Institute Hrvoje Požar, Croatia

## Introduction

Offshore wind farms are subjected to very humid, chemically aggressive atmosphere with high salinity. Corrosion rates are highest on the splash zone and upper structure, where coatings are mandatory and should be made of materials of proven reliability. Such coatings rely mainly on their barrier properties, thus offer no protection once breached. To ensure long term offshore structure protection one should apply very expensive, dynamic maintenance regime. Cost effective, economically viable solution could be found in coating system which, when damaged, can heal itself.

## Aims

The main aim is to develop a self-healing coating for corrosion protection based on microcapsules containing self-healing agent. Such system should be based on extrinsic process, which involve capsular reservoirs loaded with healing agents which could release upon rupture of the capsules (damage of the coating). Effect of additives of microcapsules on performance of existing coating matrices for corrosion protection should be investigated. Specifically, the aim is to disperse self-healing containers into matrices which are currently used in C5-M harsh marine environments for steel protection and compare their properties to conventional coatings (water based or solvent based). Considering that the coating systems for corrosively category C5 requires generally 3-5 layers of a total thickness of at least 300  $\mu\text{m}$  there is a space to introduce economically viable alternative with only 2 layers with self-healing capability. Such system, considering the thickness of the coating, would allow relatively massive nanocontainers with large amount of self-healing agent or inhibitor.

## Methods

Advanced electrochemical methods for novel coating characterization should be applied. Scanning electron microscopy for micro-surface morphology will be used. Certain industrial qualification tests will be performed to ensure suitability and durability (salt spray test, salt water immersion, adhesion study, thermal stability, etc.). The correlation between the salt spray test and Electrochemical Impedance Spectroscopy (EIS) results will be modelled.

## Expected scientific contribution

Novel cost-effective coating system could be developed. High-quality scientific results on parameters varying influence should be obtained. Namely, matrix type, substrate type, type of healing agents/inhibitors, level of intentional destruction, microcontainer size and percentage volume will be examined as influential factors on the protective properties of the coating. EIS and salt spray test correlation model should be produced.

## Keywords

Self-healing coating, offshore environment, corrosion protection

## The District Cooling Technology: How It Reacts to Population Density

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### Introduction

Experiencing harsh hot and humid weather in United Arab Emirates lead to approximately 60 per cent of energy in UAE goes toward cooling systems. A technology called district cooling can serve to reduce energy consumption by up to 50 per cent with a saving in power plant investment. While district cooling is an energy efficient solution to provide cooling to areas with high cooling density and heavy demand for air-conditioning, district cooling face challenges maintaining competitiveness over alternative cooling systems in low cooling density areas.

### Aims

The objective of this study is to analyze the parameters for improving the economy of district cooling operation in areas with low, medium and high heat demand density to assist in managing the current cooling demands and planning the future cooling demands. The consequent application of these measures will not only reduce capital and operational costs but also reduce the negative environmental impact of energy use in these areas.

### Methods

Cooling demands in United Arab Emirates shall be mapped to analyse the current situation and future trends of cooling demand in United Arab Emirates.

The research shall focus on the effect of population / cooling density on District Cooling operation and then setting the criteria for the viable district cooling with respect to population / cooling density. Setting the probable district cooling parameters that can be affected by population / cooling density; including but not limited to:

- Piping network: heat gains, operation, pipe cost, installation cost
- Power requirements for pumping system
- Chiller plant efficiency

- Chiller plant operation parameters
- The diversity factor
- Supply chilled water temperature and its control
- Building cooling load variation and it's relation to chiller plant operation and efficiency

Study in depth the criteria's to develop a hypothetical case study on the implementation of District cooling for different type of population density

Comparison of the DC parameters for above hypothetical case study against the following different cooling options unitary air-conditioning and Air cooled chillers.

### Expected scientific contribution

This research shall give new understandings on the following:

- To provide test tool to gauge which cooling option might best meet the energy needs of the buildings under various population density
- To define the link between the district cooling operation and the population density
- To define set of the most significant factors relevant to population density and quantify their relative influence on the district cooling operation.

### Keywords

District Cooling, District Heating, Cooling Density, Delta T, Diversity Factor, Chiller Plant Efficiency

# Road Transport Emissions of Passenger Cars in the Republic of Croatia

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**Mentor/s:** Zoran Lulić

**Affiliation:** The Vehicle Center of Croatia (CVH), Croatia

## Introduction

Despite many efforts, total emissions from passenger cars (PCs) have been increasing for the last few years. One reason for this is increasing the number of PCs and their exploitation activities, but another one is the ageing of the vehicle fleet since 2005. The 2008 global economic crisis affected new PC registrations, decreasing the number from nearly 90.000 that year to 45.000 in 2009. After the Republic of Croatia became a member of the EU in 2013, the number of first registered second-hand PCs exceeded the number of newly registered PCs. Trends and changes in vehicle fleet are unfavourable, the vehicle fleet is ageing, and emissions generated by those vehicles are also increasing. During this research, the vehicle fleet structure of Croatia was closely analysed and PC emissions were calculated for the period from 2007 to 2016 using COPERT 5, a Tier 3 capable program. Aside from data on air pollutants CO, NO<sub>x</sub>, PM, NH<sub>3</sub>, VOC and NMVOC the data shown includes CO<sub>2</sub> as well as fuel consumption. Tracking the PC fleet and their exploitation activities for the mentioned period has shown a negative impact of the change of PC fleet has had on total emissions.

## Aims

The aim of the study was to investigate the influence of the PC fleet structure and its activities on total emissions in Croatia for the period from 2007 to 2016. It is necessary to propose scientifically based measures to decrease emissions from PC fleet in the future.

## Methods

Road transport emissions from PCs in Croatia were calculated following the top-down approach based on the Tier 3 methodology using the programme COPERT 5. Main input data included environmental information, vehicle stock, fuel consumption, activity and circulation data (type and ratio of driving style). Environmental information included monthly

values of average minimum and maximum temperatures as well as relative humidity. The vehicle stock was exclusively limited to PCs. Activity data taken into account means annual mileage along with mean lifetime cumulative mileage, whereas the assumed circulation data taken into account means the speed and the percentage of mileage driven by vehicles of each emission standard (before Euro, Euro 1 to Euro 6) per driving mode (urban/rural/highway).

## Expected scientific contribution

Expected scientific contribution was to indicate the influence of the PC fleet structure and its activities on emissions in Croatia using real PTI (Periodical Technical Inspection) data from the CVH, the company that carries out PTI in Croatia. This method can be applied in further studies for other vehicle categories, and it can also show the influence of total or partial vehicle fleet on emissions for the observed area, country or region.

## Acknowledgments

I hereby thank to the companies Inter-net and CVH for helping me analyse data from the CVH database and prepare the input data.

## Keywords

Emissions, Emission factors, Passenger cars, COPERT

## Evaluation of Al – 2.5Wt.%Mg – 0.7Wt.%Li Alloy in as Cast Condition

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**Mentor/s:** Zdenka Zovko Brodarac

**Affiliation:** University of Zagreb Faculty of Metallurgy, Croatia

### Introduction

Aluminium (Al) and Al based alloys have been utilized in the aircraft construction since 1930 because of their unique combination of properties. However, since weight reduction and temperature performances, as well as high strength and stiffness, have become the key driving forces for new materials development and utilization in modern aerospace and space industry, the need for chemical composition redesign has been recognised. As a response to these newly defined requirements Al-Li-magnesium (Mg) alloys were developed and utilized. Besides significant reduction in density these alloys have high corrosion resistance, good weldability, high elastic modulus and static tensile strength.

### Aims

The goal of this investigation is designing of innovative Al-Mg-Li alloy and determination of solidification sequence under different cooling rates. This will enable correlation of chemical composition and significant temperatures of phase transformation and evolution with microstructure and mechanical properties. Operating under major assumption that solidification conditions influence microstructural features development and preliminary mechanical properties, mathematical modelling will be applied. The model will allow for quantification of metallurgical quality, and correlated and optimised to the aforementioned parameters, respectively.

### Methods

In order to complete this investigation successfully, several different steps have already been taken. Based on available literature and supported by computer aided thermodynamic diagram calculation adequate chemical composition was chosen, followed by determination of production process. Melting and casting procedures were adapted in consideration to low vapour pressure of Li in order to avoid its significant loss. Afterwards, metallographic sample prepa-

ration and analysis allow identification of microstructural constituents. Based on preliminary results, the next step is determination of phase transformation and precipitation temperatures and their dependence from heating and cooling rates using differential scanning calorimetry and simple thermal analysis. Mechanical properties shall be determined on macro- and micro scale. Obtained results will enable mathematical modelling of microstructural, thermodynamical and mechanical properties correlation.

### Expected scientific contribution

Modifying Al-Mg alloy with Li addition potentiated production of alloy that is 10-12 % lighter than most commonly used Al based alloys in aerospace and space industry, which is competitive to other Al-Li-Mg alloys with higher Li content in terms of density.

Furthermore, the results of this extensive investigation will enable the complete characterisation of the thermodynamical properties as well as mathematical modelling with respect to the precisely mentioned parameters and material properties.

### Acknowledgments

This investigation has been performed in the frame of financial support of investigation of University of Zagreb (TP167 Design and characterization of innovative engineering alloys) and collaboration between University of Zagreb Faculty of Metallurgy and University of Ljubljana Faculty of Natural Sciences and Engineering.

### Keywords

Al-Mg-Li alloy, solidification sequence parameters, microstructural characteristics, mechanical properties, mathematical modeling

## Mechanical Ventilation Analysis in Underground Car Parks

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**Affiliation:** INVENTO PRO, Croatia

### Introduction

Various ventilation systems are available for carbon monoxide extraction and smoke extraction in a case of fire in underground car parks, jet thrust fan systems, ducted ventilation systems and systems with extract fans. These systems depend not only on the rules applied during the design but also on the underground car park architecture. The main task of the mechanical ventilation system is to extract harmful exhaust gases and smoke from an underground car park. Numerical modelling is greatly important in the design of fire and smoke extraction and mechanical ventilation and a useful tool to determine air flow patterns, temperature fields, smoke stratification and clear layers for safe human evacuation and safe firemen approach. Temperature fields, streamlines and visibility can be checked separately for any time interval in any section of an underground car park. Case studies help to improve understanding of car park mechanical ventilation designs. They also enable comparing various different physical, fire and smoke dispersion models, heat and mass source modelling and fire scenarios as well.

### Aims

The aim of this research is to analyse phenomena occur in the underground car parks in a case of fire, and influence of installed mechanical ventilation in the day-to-day situation and in a case of fire. The main objective is an analysis of air stagnation areas, the influence of fans positioning in the underground car parks to reduce and eliminate air stagnation areas and, finally, mechanical ventilation system optimisation. One of the numerical modelling challenges is to recognise those fans that do not contribute overall clear layers in the enclosure. Additional aims are to analyse the interaction between other active and passive fire protection systems in the underground car parks and finally human behaviour in the accidental situations.

### Methods

Numerical and experimental methods will be used in the research. Numerical modelling will be used to model and simulate fire growth, air flow, temperature fields, streamlines, air stagnation areas, clear layers, smoke stratification and carbon monoxide and smoke extraction ventilation efficiency in the underground car parks. The experimental method will be used to research the interaction between smoke extraction ventilation system and sprinkler system as a part of active fire protection systems in an underground car park. Finally, using the software for people evacuation from the buildings will connect the numerical and experimental results with the human behaviour in the accidental situations.

### Expected scientific contribution

This research is expected to contribute understanding of phenomena occurring in underground car park fires, how installed mechanical ventilation system can help to reduce the harmful influence of fire on the underground car park ceiling, walls and beams and to avoid concrete spalling. This is multidisciplinary research, connecting mechanical and fire engineering. It is expected that the additional contribution of this research will be to help human evacuation from an underground car park and safe approach to the firemen.

### Keywords

numerical modelling, underground car park, mechanical ventilation, extraction efficiency

## Harmonized Model for Carbon Footprint Calculation of Organizations

**PhD candidate:** Željko Jurić

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### Introduction

A scientific consensus regarding the impact of the anthropogenic greenhouse gas emissions on climate change, with significant contributions of emissions covered by the carbon footprint of organizations, has been achieved on an international level. In the global attempt to meet the international commitments for the reduction of greenhouse gas emissions, organizations started to calculate their own carbon footprint and try to find and implement its mitigation measures. However, the results of these attempts cannot be well compared because of applied different approaches, which usually use different range of input data and different emission factors. In order to obtain more comparable results, it is necessary to harmonize the approach for calculating the carbon footprint.

### Aims

The main aim of this research is to develop and apply the carbon footprint calculation model for organizations, by adapting the French Bilan Carbone® model to Croatian conditions. For the purposes of the model, a national database of emission factors will be developed, which will consist of at least 150 national and at least 150 European emission factors. The calculation of the carbon footprint is only the first step, which will allow organizations to choose and implement a well-balanced set of cost-effective measures for carbon footprint reduction. The harmonized model for carbon footprint calculation will be tested on several private and public organizations in Croatia.

### Methods

The carbon footprint is a significant component of environmental footprint and could be defined as the total amount of greenhouse gases, directly and indirectly, emitted in the atmosphere by a project, an organization, or a product. The model will be designed to estimate the greenhouse gas emissions of organizations, based on the

Life Cycle Assessment approach completely in accordance with international standards – the GHG Protocol and ISO standards (ISO 14064 and ISO/TR 14069). This approach involves the calculation of all direct and indirect emissions from activities for which the organization is responsible, and all other activities of input and output flows on which the organization is dependent.

### Expected scientific contribution

There are numerous models for carbon footprint calculation, using different range of input data and emission factors, and thus the results cannot be adequately comparable. It is expected that this research will show and propose a harmonized model for calculating the carbon footprint of organizations. Establishing of a harmonized model on national, European and even global level, would obtain more comparable results and benchmarks for different kinds of organizations.

### Acknowledgments

This research is the part of the Clim'Foot project "Climate Governance: Implementing public policies to calculate and reduce organizations carbon footprint", co-financed through the LIFE program. This help is gratefully appreciated.

### Keywords

Carbon footprint, greenhouse gas emissions, emission factors, climate change, Bilan Carbone® model

# Numerical Assessment of the Interference Resistance for Multihulls

**PhD candidate:** Andrea Farkas

**Mentor/s:** Nastia Degiuli

**Affiliation:** Faculty of Mechanical Engineering and Naval architecture, Croatia

## Introduction

Growing demands for higher energy efficiency have led to significant increase in interest for multihull configurations in civil, recreational and military fields. Even though many theoretical, numerical and experimental studies have recently been made, multihull resistance prediction still has a degree of uncertainty. Total resistance of multihull cannot be determined as the sum of the total resistance of each hull, because interference resistance should also be taken into consideration. As interference resistance is a very complex phenomenon, profound understanding of the flow in inner and outer region of multihull configurations is necessary to effectively assess its value. Advancement in the computer science and numerical computation methods has led to improvement in accuracy and efficiency of Computational Fluid Dynamics (CFD) methods. Consequently, CFD methods have become useful tool for investigation of multihull hydrodynamic characteristics. In the past, the most commonly used methods for interference resistance prediction were experimental methods and CFD methods based on the potential flow theory. Experimental methods are very expensive and time consuming, while potential flow methods neglect viscous effects and therefore cannot assess interference resistance correctly. CFD based on the viscous flow can capture turbulent and vorticity effects, as well as nonlinear free surface effects. Within this research, numerical study of interference resistance is performed for different catamaran configurations.

## Aims

In order to investigate interference resistance numerically, advancements in numerical modelling should be made. The aim of this research is to develop reliable numerical model for the determination of interference resistance. The emphasis is put on improved turbulence modelling, viscous and wave interactions between hulls for intermediate and high Froude numbers.

## Methods

Numerical simulations of viscous flow are performed utilizing Reynolds Averaged Navier-Stokes (RANS) equations within commercial software package STAR-CCM+. Finite Volume Method (FVM) is used to represent and evaluate partial differential equations in the form of algebraic equations. The solution domain is subdivided into finite number of control volumes by an unstructured grid. Volume of Fluid (VOF) method combined with High Resolution Interface Capturing (HRIC) scheme is used to track sharp interfaces and locate a free surface in free surface simulations.

## Expected scientific contribution

Numerical simulations based on viscous flow are used for the determination of multihull hydrodynamic characteristics, as well as the detailed representation of the flow in inner and outer region of multihulls. In this research, numerical modelling techniques will be developed in order to obtain reliable numerical model for accurate prediction of the interference resistance. Thus, new insight into the interference phenomenon could be obtained.

## Acknowledgments

I wish to thank prof. Degiuli for her constant encouragement and support.

## Keywords

Computational Fluid Dynamics (CFD), Volume of Fluid (VOF), interference resistance, multihulls

# The Impact of Personal Attributes on Increasing the Success of Complex Projects

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**Affiliation:** LEGO Group, Denmark

## Introduction

Project management has evolved immensely over the last few decades and the preliminary project management triangle (time, cost, quality) seems no longer to be adequate. Professional literature, which is exploring the components of project success, is mainly researching input and output sides of success. The output side focuses on the success criteria, which represent the base values, based on which the project success can be evaluated. At the same time, input side is focusing on the critical success factors. Critical success factors are in fact "those few things that must go well to ensure success for a manager or an organization." Setting and realizing these factors can lead to a higher possibility of project success. One of the most important critical success factors is defined to be the competencies and the leadership style of the project leader. Recently, the biggest change in project management has been a shift away from learning about scheduling and the technical skills for managing projects to a recognition that people matter on projects.

## Aims

In order to achieve the objectives set by this thesis – knowing the limits of professional literature – it is important to explore and map the personal attributes of the project team and the project manager and the relationship between them. Also, it is important to examine the impact of those characteristics on project success. In this way, the thesis aims to show the relationship between the personal attributes of the whole project team and the project success, expressed using the critical success factors. On the other hand, it tries to explain the impact of the personal attributes of the project team in different project management frameworks, as well as the impact of the personal attributes of a traditional and a modern project manager on project success.

## Methods

Research of the existing literature will be used for formulation of the hypothesis, based on the current approach towards the impact of personal attributes on the project success. Qualitative and quantitative methods of collecting data will be used to prove the set hypothesis. For quantitative methods, Likert scale will be used during information collection and correlation analysis will be used to interpret the results. Semi-structured interviews will be used during 1:1 interviews with project managers and questionnaires will be used for the whole project teams.

## Expected scientific contribution

Based on the available literature, it is possible to identify six personality attributes but their impact on the project success has not been identified yet. This thesis will define the personal attributes that need to be present in the project team, in order to increase the success of complex projects. As such it can be beneficial to all project managers in the beginning of the project when choosing the project team members in a combination with a project management framework, and during the project for an easier progression of the project, but at the same time to organizations when hiring a project manager.

## Keywords

Project management, Complex projects, Project Management Framework, Project Success, Personal Attributes



# Energy, Environmental and Economic Analysis of Different Waste Management Systems

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## Introduction

Waste management is defined by all the activities including collection, transport handling, treatment, material and energy recovery and disposal of waste. Solid waste causes endangering human health, harming the environment, increasing greenhouse gas emissions, climate changes, depletion of ozone layer, nuisance through noise and odors and overmuch wasting of the natural resources. Therefore, the European policy encourages waste prevention, sustainable use of natural resources, protection of ecosystem and circular economy. The waste hierarchy is a preferential order of waste treatment options that aims to reduce environmental impacts by prioritizing prevention, reuse, recycling, and recovery over landfill. Unfortunately, landfill is most commonly used and accounts for approximately 95 % of the total collected municipal solid waste worldwide.

Published studies based on LCA (Life cycle assessment) analysis are primarily concentrated in Europe with little application in developing countries, such as Croatia.

## Aims

This research will provide a detailed and comprehensive analysis of two different solid waste management systems "Ponikve eko otok Krk" and "Mariščina". "Ponikve eko otok Krk" is system in which dominates recycling and re-use of products while "Mariščina" is mechanical-biological treatment facility which main output is refuse derived fuel. The analysis will include energy, environmental and economic assessment of individual waste management system. Indeed, the aim of research is quantification and comparison of obtained economic, energy and environmental parameters.

## Methods

Start of research includes visiting "Ponikve Krk" and "Mariščina" and getting acquainted

with their work as well as collecting of relevant data. Since the activities in waste management can be divided in four categories: collecting, transport, recovery and disposal, following data will be considered: energy consumption per individual processing sector, water consumption, size of population, energy consumption of fleet, distance traveled by the vehicle, amount of collected waste, operational costs...

Later a corresponding statistical analysis as well as Cost-Benefit analysis of implemented systems will be made. The emission of harmful gases into the environment will be calculated and system's energy and mass flows will be shown. In this way, two previously mentioned systems will be compared. The obtained results will be evaluated by LCA analysis using SimaPro software package.

## Expected scientific contribution

Expected scientific contribution is an optimization of existing waste management systems. Moreover, this study should be framework for upcoming waste management systems. It will give quantification of energy, environmental and economic assessment.

Further research should be intent to the optimization model development for solid waste management system.

## Keywords

waste management, recycling, mechanical-biological waste treatment, LCA, cost-benefit analysis

## Implicitly Coupled Turbulence Models

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**Mentor/s:** Hrvoje Jasak

**Affiliation:** FAMENA, Croatia

### Introduction

Implicitly coupled pressure-velocity algorithms for incompressible flows introduced a significant increase in convergence rates for the velocity and pressure equations, compared with corresponding segregated algorithms (e.g. SIMPLE or PISO). However, when implicitly coupled solvers are used for turbulent flow simulations, convergence rates are often limited by segregated treatment of turbulence model equations. Despite their relatively simple mathematical representation, turbulence model equations present serious numerical difficulties, among which are non-linear coupling, convergence and positivity preserving challenges. Furthermore, in the process of convergence, non-physical solutions, namely negative values of the turbulence quantities may appear even if the equation set analytically guarantees to remain positive. Therefore, stability and boundedness of the implemented turbulence models is becoming an active and challenging field for research.

### Aims

The aims of this work is to derive general conclusions regarding impact of implicit coupling of two-equation turbulence models on overall calculation performance.

### Methods

The method was previously implemented in foam-extend (the community-driven fork of OpenFOAM) using incompressible k-epsilon and k-omega SST models and it was successfully validated for the backward facing step and for the NACA 4412 case. The previous benchmark study was carried out on structured and relatively small grids, therefore the new analysis will contain benchmarking on large three-dimensional unstructured grids. Furthermore, the comparisons will be carried out for both implicitly coupled and segregated pressure-velocity algorithms in order to obtain a general conclusion about influence of implicit coupling

of turbulence models on overall calculation performance.

### Expected scientific contribution

The work is suppose to quantify the trade-off between the performance enhancements and increased memory usage when implicit turbulence models are used for industrially applicable flow problems.

### Keywords

Block Coupled Solvers, Turbulence Modelling, Benchmarking

## Influence of Worm Gear Pitch Error on the Gearing Durability

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### Introduction

When it comes to the transfer of large torques and precise rotational movements, gears are the most widely used machine element. A special place among them belongs to the worm gears, due to their ability to transfer large torques while maintaining the design compact. However, a dominant sliding motion in relation to the rolling, combined with the high contact pressure often results in the intensive wear and pitting damage of the flanks. Currently used calculation models and standards assume the fully conjugated worm and worm wheel tooth profiles ensured by the running-in phase. On the other hand, recent studies indicate that the worm wear does not fully eliminate the pitch error; meaning that current models overlook the uneven load distribution across the meshing teeth pairs. As the load distribution is tightly linked to the pitting occurrence and topology, to gain new insight the research of the worm pitch error impact on the worm gearing durability is suggested.

### Aims

The research aim is to improve the worm gear load calculation model by accounting for the worm pitch error. Worm pitch error causes the uneven load distribution across the meshing teeth pairs, resulting in higher local contact stresses responsible for the increased flank damage. To reach the goal, relation between the worm pitch error and the increased pitting occurrence will be further examined and defined.

### Methods

Joining the mesh stiffness, the tooth bending and the contact pressure deflection expressions with the pitch error will yield the exact load distribution expressions. Since the empirical research is often used in the field of gear strength and durability assessment, analytically found results will be experimentally confirmed. Following the comprehensive worm measurements, lower

accuracy grade units will be compared against the more precise ones. Units will also be measured after the experiment is concluded.

### Expected scientific contribution

By including the worm pitch error in the load distribution model, more precise pitting topology prediction will be possible. Since the worm transmissions are able to properly operate with pitting covering up to 40 % of the flank surface, more accurate calculation model will allow for the more precise durability prediction. Moreover, use of lower safety factors will be possible; thus avoiding the design of oversized machine elements.

### Keywords

Worm gear, pitch error, contact pressure, surface durability, pitting.

## Improvement of the Energy Planning Process for the Development of the Local and Regional Sustainable Energy Action Plans

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### Introduction

Climate change caused by human activities and their successful mitigation and adaptation to consequences are one of the crucial issues of humanity in the 21<sup>st</sup> century. One of the widespread solutions for reducing human influence on climate are local and regional initiatives, which create energy plans for sustainable development. At the development of energy plans, the most common issue is non-conformity between the available data and methods for the analysis of the current energy consumption, planning and preparation of reference and alternative scenarios for reduction of energy consumption and greenhouse gas emissions, and influence and responsibility of local and regional actors.

### Aims

The aim of this research is to upgrade a method for local and regional energy planning through a suitable choice of measures and alternative scenarios for the reduction of CO<sub>2</sub> emissions. To question the possibility of interaction and integration of measures through development of scenarios containing measures and optimise their use on local and regional level considering economic, social and environmental criteria

### Methods

Analysis of the most used measures for the reduction of energy consumption and CO<sub>2</sub> emissions, which are used in Sustainable Energy Action Plans will be done. It will be determined the potential influence of each measure on the reduction of energy consumption and CO<sub>2</sub> emissions, and on other criteria like local employment, improvement of air quality, economic and trade balance, energy production diversification, energy import dependency, and etc. Mutual interaction between measures, which have an influence on the total result of energy consumption reduction, will be done through simulation on specific cases in which interaction between

the simultaneous implementation of measures will be analysed. EnergyPLAN, HOMER, H2RES, or other energy planning software will be used for the simulation. Depending on the results of the interaction between measures, matrices of measures will be developed, which will satisfy the basic criteria for the reduction of energy consumption and CO<sub>2</sub> emissions. The matrices of measures will be grouped according to available financial resources and mechanisms. The merit order for implementation of measures will be established by using the marginal cost abatement curve. In this way, the selected matrices of measures will provide maximal fulfilment of economic, environmental and social criteria for limited amount of financial resources. The evaluation of matrices of measures will be done through indicators, like SDEWES index.

### Expected scientific contribution

It is expected that this research will result in an upgrade of a method for the analysis of the approach to the energy planning on local and regional level considering economic, environmental and social criteria. Development of an innovative approach by using marginal cost abatement curve in the development of Sustainable Energy Action Plans on the local and regional level. Development of standards for implementation of measures and alternative scenarios on the local and regional level for stakeholders and decision makers.

### Keywords

Energy planning, local level, environmental sustainability, economic sustainability, sustainable energy action plans

## Numerical Modeling of Quenching Process

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### Introduction

In order to achieve the desired mechanical properties of metallic alloys to meet specific design requirements, the adjustment of microstructure is necessary. To accomplish this, the metallic part is subjected to quenching process. Such process is followed with the complex physics which makes the computations difficult and experiment-dependent. However, the developments in computational physics together with the rise in computer technology provide the basis to overcome the obstacles. Therefore, the aim of this research work is to develop a method capable to perform the computations of quenching process without the need for the input data obtained by measurements.

### Aims

As outlined above, the goal of this research project is to develop a numerical method capable to capture the temperature evolution in a solid during the immersion quenching process. The developed method would enable to perform the computation of quenching process without the need for experimentally determined input temperatures. This implies accurate numerical modeling of boiling phenomena, since all boiling modes are present during the immersion quench cooling process. This method would be implemented within OpenFOAM C++ library.

### Methods

This research is carried out using numerical modeling approach, while the validation would be performed by comparison of the obtained results with the experimental data. The employed numerical method is the finite volume method (FVM) because it expresses the conservation laws in integral form and thus is a natural choice for numerical modeling of heat transfer and fluid flow problems. Since the temperature evolution in a solid is influenced by the phenomena occurring in the flow, this problem belongs to conjugate heat transfer (CHT) class

of problems. Thus, the temperature field in the solid is obtained by solving the heat conduction partial differential equation, while the accompanied fluid flow is modeled using an Euler-Euler approach. Furthermore, to successfully model the boiling regimes in the flow, the correlations available in literature would be used.

### Expected scientific contribution

The outcome of this research project is the numerical method which would enable computation of fluid flow and heat transfer during the immersion of a hot solid into water. The main contribution would be in the field of accurate numerical modeling of phase change phenomena present in the process, since it has the prevailing influence on the results. This leads to accurate prediction of temperature fields in the solid during the complete process and especially at the beginning of the process. Also, this method would enable to capture the corresponding temporal and spatial variations of heat transfer coefficient. In conclusion, it is expected that the scientific community as well as the industrial users would benefit from this method by achievement of more efficient heat treatment process.

### Keywords

Immersion quenching, Conjugate Heat Transfer, Multiphase flow, Boiling

## Smart Factory Model Based on Lean Management Principles

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### Introduction

Smart factory is a new concept that is connecting machines, storage systems and manufacturing equipment into Cyber-Physical System in order to exchange information electronically to respond to new trends on the market. Optimal use of enterprise resources, increased productivity and efficiency, improved quality and flexibility of manufacturing and service processes are main features of the Smart factory concept. The main goal is to develop a smart factory model adapted to the conditions in Croatia and to increase the efficiency of our companies through the improvement of manufacturing and logistics processes and reduce their lagging behind the competition in Europe and the world. In the process part of the model, the concept of Lean Management will be applied in order to achieve greater efficiency of the process.

### Aims

In the past few years, the European Union industry is experiencing decrease in competitiveness and that reflects in reduction of working hours, downsizing workers and factories that fall behind. Similar situation is happening in Croatian manufacturing companies and through the realization of the goals from this paper these trends would be alleviated. Main goals of the dissertation is first to describe the current way of process organization in Croatian manufacturing companies than to recognize the measurability and metric for monitoring efficiency of the processes. It is important to reduce the gap in processes functioning between Western and Croatian companies and to develop an approach in managing logistics and other manufacturing processes in a smart factory model. In addition, one of the goals is to develop a system for monitoring the efficiency of logistics and other processes in a smart factory.

### Methods

As one of the aims of this dissertation is to improve innovative, technological, organizational, process, logistic, information-communication and human resources, first it was necessary to analyze the existing state of manufacturing companies in Croatia. The research was conducted through a survey that was forwarded to the manufacturing companies in Croatia. Second part of the research will include the development of a smart business model based on requirements of industry 4.0 and the use of modern computer-communication technologies (ICT). Special part of this phase of research will be to set production and logistics processes and monitor their efficiency. In the third phase, a testing of a smart factory model will be conducted in one manufacturing company. In the final phase, a smart factory model and selected concepts will be generalized.

### Expected scientific contribution

The main scientific contribution is reflected in forming an original smart factory model based on Lean principles.

### Acknowledgments

I would like to thank the company Culmena which will ensure material and financial resources for the purpose of making this dissertation.

### Keywords

Industry 4.0, smart factory, process approach to enterprise, lean management, logistics.

## Analysis of Coupled Dynamical Systems

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### Introduction

Dynamical systems are becoming more complex and thereby demands in terms of robustness and efficiency are set high when synthesizing such dynamical systems. Common paradigm, when coupled dynamical systems are modelled, includes mathematical modeling of each subsystem described with system of constitutive relations. These relations usually yield system of partial differential equations (PDE). PDE are later approximated with discretization tools such as finite element method (FEM) to achieve system of ordinary differential equations (ODE). Discretized subsystems are then coupled into complex dynamical systems. When observing such systems one has to answer questions regarding validity and accuracy of mathematical model. Since each discretized subsystem carries approximation error the question arises: "When is discretization of each subsystem good enough to maintain accuracy and validity of resulting coupled dynamical system?".

### Aims

Robust control theory demands uncertainty modelling. Aim is to formulate uncertainty model of an individual subsystem that describes discretization error. When doing so, dynamical systems will be analyzed using interconnected plants consisting of linear time invariant plants (LTI) with feedback. Feedback of the system includes uncertainties. The fact that each subsystem is coupled with other subsystems will (hopefully) be used to reduce conservatism and provide better uncertainty model.

### Methods

In modern robust control theory, integral quadratic constraints (IQC) are often used for modelling wide variety of uncertainty classes. Together with other mathematical tools and models, such as linear matrix inequalities (LMI), dissipation theory and convex optimization, IQC will be used to model uncertainty due to discretization.

### Expected scientific contribution

Resulting a-priori error estimator should provide efficient and robust tool for analyzing discretized coupled dynamical systems. This method is efficient since computationally undemanding coarse mesh can be used for discretization and linear systems of equation are solved. The resulting model (LTI plus uncertainties) is suitable for robust control since the uncertainty model is less conservative.

### Keywords

coupled dynamical systems, a priori error estimation, uncertainty modeling

# Dynamic Stability of a Vertical Take-Off and Landing High Aspect Wing Aircraft in Operational Conditions During Vertical Flight Phase

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**Mentor/s:** Milan Vrdoljak

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## Introduction

Unmanned aerial vehicles (UAVs) have been used for decades in military applications, but recently they have started entering commercial and civilian domain, too. The commercial applications of UAV's are immense and range from precise agriculture, delivery of goods, industrial inspections and search and rescue operations. There are two main categories of UAV's on the market today: multirotor and fixed wing UAV's. None of these alone is fully suitable for commercial or civilian use. Multirotors, that are vastly used today, while offering fully autonomous flights, are not energy efficient and have low speed. Fixed wing UAV's, on the other hand, are much more efficient but require operator's assistance and runways for take-off and landing. Combination of these configurations is a Vertical Takeoff and Landing (VTOL) fixed wing UAV that has both autonomous take-off and landing ability and the fixed wing advantages. VTOL UAV's can be subdivided into two main groups: tilt-rotors where the rotors tilt during the vertical flight regime, and tilt-wings, where the assembly of the wing tilts together with rotors. The scope of this thesis will be the dynamic stability of a tilt-rotor VTOL UAV.

## Aims

Dynamic stability and control of the VTOL UAV in the vertical flight phase and transition is a complex non-linear problem. Efficient dynamic model means optimized use of energy and a more efficient aircraft operating in extreme conditions, as well as expanded potential spectrum of application, which affects the competitiveness of VTOL aircraft on the market. The aim of this research is to expand the model of dynamic stability of a VTOL tilt-rotor aircraft, with at least three tiltrotors, for the vertical flight phase in operating conditions that can be considered analog to the transition phase of the flight with the ground effect present.

## Methods

Research will include analysis of the existing literature, which will become basis for formulation of the mathematical model of a transitional flight with ground effect and the computer simulation of the problem. Experimental part will be conducted to test the established mathematical model with its implementation on the microcontroller of a pre-built VTOL prototype aircraft. Theoretical and experimental part of the research will be interwoven iteratively until the appropriate mathematical formulation of this complex non-linear problem is found.

## Expected scientific contribution

Based on the available literature, it is possible to define the the most challenging phase of the flight, the transitional phase, but it is usually solved with parametrization between vertical and horizontal flight stability and control algorithms. Vertical flight of a VTOL in the take-off and landing phase, in the realistic conditions, can be considered as a transitional phase since the true airspeed is significant. This thesis is focusing on the development and testing of the efficient transitional stability algorithm for high aspect ratio wing tilt-rotor VTOL UAV's and it will be built into flight controller of a commercial VTOL UAV, thus increasing its competitive advantage.

## Keywords

Unmanned Aircraft, Transit Flight VTOL UAV, Dynamic Stability VTOL UAV, Tilt-rotor VTOL UAV



# Energy and Environmental Features of Ships for Transport Liquid Natural Gas

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## Introduction

Floating prices of oil, tendency to reduce the shipbuilding and exploitation costs and increase environmental awareness at the global level are often in front of the ship and marine power systems designer impose contradictory demands. At the same time, the liquefied natural gas (LNG) market, which is increasingly being used as propulsion fuel on ships, is in continuous expansion and as a consequence has the construction of larger LNG ships. In recent years, the design environment of marine power system has considerably changed through the mandatory application of the Energy Efficiency Design Index (EEDI). Most of the existing LNG fleets use diesel engines driven by diesel fuel and mechanical propulsion chain while the marine power system development trend is developing integrated power systems, offering greater energy efficiency, and using liquid natural gas as fuel for prime movers environmental eligibility.

## Aims

The aim of the research is to develop procedures for design high degree energy efficient and environmental eligible power system of the LNG ship. An integrated power system with electromotive propulsion will be analysed, using LNG as propulsion fuel, energy efficiency of propulsion chain with regard to various types of propulsion aggregates and electromotive propulsion systems, influence of factors for EEDI definition, impact of navigation conditions on design solutions in the propulsion system of the ship and the impact on the environment depending on the exploitation conditions.

## Methods

The basis of the research will be a computer model, which requires the synthesis of existing scientific findings from studies dealing with the design of the ships for liquefied gas transport and marine power systems with particular em-

phasis on those who use liquefied gas as propellant fuel. An analysis of the power systems of the existing LNG fleet will be carried out as well as an analysis of the influencing factors on the parameters for assessing energy efficiency and environmental eligibility as the basis for making a computer model that will along with traditional parameters take environmental parameters as well as operational. Based on a created computer model, the performance of marine power system of ships that have already been built will be evaluated, according to different criteria, and offered alternative solutions that meet rigorous environmental rules. At the end, assesment of the impact of the LNG ships fleet on the environment depending on the different configurations of marine power systems.

## Expected scientific contribution

Elaborate designing procedures of a high degree energy efficiency and environment acceptability marine power systems of LNG ships, through the impact analysis of the various configurations of the marine power systems on the energy and environmental ship features, taking into account not only the design but also the operational features of the ship.

## Keywords

Marine power system, LNG, EEDI, energy efficiency, environmental eligibility

## Design for Additive Manufacturing Methodology

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### Introduction

Additive manufacturing (AM) is relatively new, fast growing, manufacturing process that enables adding material on workpiece precisely where it is needed. AM evolved from only rapid prototyping technology to everyday manufacturing process and with it brought new unique design possibilities in design and product development process. The unique possibilities are: shape, hierarchical, functional, and material complexity. Designers can use these possibilities to create new and innovative products, with better functionalities and performance compared to products manufactured with conventional technologies. The designers are currently facing the lack of common methodology oriented on using AM in product development process to help them utilize possibilities offered by AM while creating new products. For this reason there is a need for the development of a new design method, inside the area of Design Theory, oriented on AM – Design for Additive Manufacturing (DfAM). The DfAM method should contain the design guidelines and instructions inside a common framework and be used as a tool by the designers for development of AM oriented products.

### Aims

The aim of this research is to develop an AM oriented design method that can be used in product development process for products manufactured with AM processes. The goal is to give the designers the tool they need to utilize AM possibilities and optimize their product in functionality, performance and manufacturability. Additionally, the DfAM method that needs to be developed, should boost the designer creativity in early phases of design process, such as conceptual phase, and with it enable development of new and innovative products, with better functionalities and performance compared to products made with conventional manufacturing.

### Methods

In this research firstly existing design methods and tools in the area of Design Theory will be analysed. The next step will be to study and analyse existing AM processes, their possibilities and constrains. The new DfAM method will be developed using Design Research Methodology (DRM) approach. In the end, the developed method will have to be validate with experimental research.

### Expected scientific contribution

It is expected that this research will contribute to existing knowledge in area of Design Theory and product development with focus on AM. It will either modify existing methods and tools or create new ones. In the end it will provide the tools that designers can use in their everyday tasks of product development.

### Keywords

additive manufacturing, Design for Additive Manufacturing, Design Theory, product development

# Planning the Energy System for the Integration of Renewable Energy Sources and Demand Response Technologies in the Energy Market Environment

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## Introduction

The integration and coupling of electricity markets influences the energy prices, which determines the middle and long term planning perspective for the energy systems. The existing and future electricity markets are subject to physical limitations in the presence of variable renewable energy sources, demand response technologies and available network transmission capacities. Therefore, the transmission capacities, balancing effect of demand response technologies visible as the reduction of export and critical excess electricity production (CEEP) and installed capacities of variable renewable energy sources (VRES) will be examined as factors which influence the market coupling of trading zones.

## Aims

The aim of the research is to develop the method which would demonstrate the increase in overall welfare in the zones (energy systems) between which the exchange is considered, represented as the change in the costs of operation of the system before and after the coupling, while taking into account the dynamics of VRES integration followed by the use of demand response technologies. Particular problem is identified in zones which are not well connected to the grid, for example in island communities.

## Methods

Scenarios with high integration of VRES in the power systems of particular zones are examined with the goal to determine the ability of the system to integrate locally available VRES through demand response and the ability of current transmission systems to facilitate the coupling and, in future scenarios, upgrades needed to enable this process. EnergyPLAN tool is used to compare scenarios with different dynamic of

integration of VRES and demand response technologies, using the MultiNode tool expansion of EnergyPLAN.

## Expected scientific contribution

A novel method will be presented, which will enable planning in the selected zones (representing an island systems or specific geographic areas), according to the local energy sources potential, taking into account the dynamic of VRES integration and connection between systems, as well as appropriate dynamics of demand response technologies integration.

## Acknowledgments

The author wishes to express gratitude to the PRISMI project, co-funded by the European Regional Development Fund, and SDEWES Centre for funding of the research.

## Keywords

power systems planning, electricity market, demand response, dynamic of integration, renewable energy integration

## Research of Start of Plastic Flow on Niobium Microalloyed Steels

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### Introduction

The start of plastic flow of niobium microalloyed steels indicates significant difference related to the same low carbon steels without niobium. Using methods of static tensile testing, thermography and visioelasticity with digital image correlation, it was determined that the occurrence of inhomogeneous deformation at the start of plastic flow in niobium microalloyed steels is related to the Lüders bands. Phenomenon of the Lüders bands are intensively studied, but current knowledge indicates lack of full explanation of the Lüders bands formation and propagation cause. Different interpretations of influential parameters on their formation and propagation were investigated in different materials such as low carbon steels, aluminium alloys and shape memory alloys. This research refers to an analysis of specific behaviour of microalloyed steel at the start of plastic flow of material. The idea for material flow during cold deformation investigation resulted from the fact that problems related to inhomogeneous deformations occurred in specific conditions during cold drawing tubes cannot be completely explained and resolved.

### Aims

The aim of this research is to determine the influence of chemical composition, microstructure and strain rate on Lüders bands formation and propagation. The content of microalloying element niobium, size and distribution of niobium precipitates, as well as differences in the steel microstructure will be studied. Obtained results will enable mathematical model for Lüders bands occurrence prediction, as well as determination of the influencing parameters on their formation and propagation.

### Methods

This research will be performed with experimental and numerical methods. Quantitative and qualitative information of material flow and

changes during deformation will be obtained using modern research methods such as thermography, visioelasticity with digital image correlation and the static tensile testing. Detail analysis of steel microstructure at the plastic flow start and in particular significant deformation stages will be obtained using scanning and transmission electron microscope.

### Expected scientific contribution

Expected scientific contribution is to explain the microalloyed steel specific behaviour at the start of the cold plastic deformation. A special contribution is in the research of influential parameters during formation and propagation of the Lüders bands and influence of size and distribution of niobium precipitates at the material flow and stress distribution in the deformation zone. This research enables determination of the mechanism of formation and influenced parameters on occurrence and propagation of the Lüders bands. The mathematical model will provide prediction of the occurrence and propagation velocity of the Lüders bands.

### Acknowledgments

This research is fully supported by Croatian Science Foundation under the project IP-2016-06-1270 (Study of the beginning of plastic flow of metals during cold deformation).

### Keywords

Microalloyed steel, start of plastic deformation, thermography, digital image correlation, Lüders bands

# Simulation of Nitrogen Oxides' Formation in Solid Fuels Combustion

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## Introduction

Despite the rapidly rising share of newly installed renewable power capacities, conventional power plants are likely to retain a considerable importance in the future energy mix. However, the stringent regulations concerning emissions limit the operation of these power plants, setting the restriction on the pollutant amounts in the flue gases, and at the same time present an opportunity for usage and development of the advanced techniques for the emissions reduction.

## Aims

Today, numerical simulations have become a standard tool for inspecting a wide variety of physical and chemical phenomena, and are used for getting a better insight into the processes in the combustion systems.

The formation of the nitrogen oxides in the combustion systems presents a threat to the environment and population health. They are significant contributors to the formation of photochemical smog, tropospheric ozone, acid rain-fall, greenhouse effect and the depletion of the ozone layer. In this work, the implementation of the production mechanism for solid fuel nitrogen oxides will be presented. It has a predominant influence on the overall nitrogen-containing pollutants formation in the solid fuel combustion systems while applying only the usually prevalent thermal mechanism is not sufficient to accurately predict the pollutant concentrations.

## Methods

The AVL FIRE software was used to simulate solid fuel combustion process in a simplified three-dimensional geometry of the commonly used experimental system – drop tube. Flow field, the introduction of the solid fuel particles in the Euler-Lagrangian framework, pyrolysis and combustion of the fuel and the effect of turbulence are some of the phenomena that were modelled in the simulation.

As the extension of the solid fuel combustion model, presented mechanism takes into account the emission of the volatile species from the fuel particle into the gas phase, formation of the intermediate species and their reaction towards the final products. Just as well, the heterogeneous char reactions are considered and incorporated into the model as well, resulting in a simplified chemical model for nitrogen oxides formation.

## Expected scientific contribution

The obtained simulation results for solid fuel combustion and pollutant emission from the simple drop tube geometry are analysed and compared to the experimental data.

The implemented chemical model for prediction of the nitrogen oxides' formation in solid fuel combustion systems could be used as a tool for better understanding the intertwined influences of geometry, coal composition, flow field, temperature and other parameters on the pollutant formation.

## Acknowledgments

This work has been fully supported by Croatian Science Foundation.

## Keywords

NO<sub>x</sub> emissions, combustion, solid fuel, CFD

## Steady Rans Modelling of the Homogeneous Atmospheric Boundary Layer

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### Introduction

In the recent years numerical modelling of the neutrally-stratified homogeneous atmospheric boundary layer (ABL) has been part of many investigations. Although large eddy simulation (LES) has been also used often in the latest time, Reynolds averaged Navier-Stokes (RANS) approach is still first choice considering the computational modelling of the ABL. The aim of recent investigations was to achieve the homogeneous flow through the computational domain together with proper distribution of the flow properties, such as mean velocity, turbulent kinetic energy and dissipation rate. This was usually achieved by altering the turbulence model equations and applying the proper boundary conditions.

### Aims

The aim of research is to develop a computational approach that will be capable of resolving physics of the ABL flow by implementation of the new source term in the momentum equation, rather than altering standard turbulence model equations. Hence, such approach will allow independent selection of various RANS models. In the end model will be tested by performing various simulations characteristic for the wind engineering flows.

### Methods

The computational model will be implemented in an open source CFD software OpenFoam and tested on the ABL flow in an empty domain for rural, suburban and urban terrain type. The results will be compared with available experimental measurements in order to approve that model ensures homogeneity of the flow and proper distribution of all relevant physical properties. The effect of an additional body force implemented in the momentum equation will be discussed and model will be validated on the ABL flow over prismatic obstacles and

hilly objects submerged into the ABL. Finally, model should provide accurate computations of the more complex wind engineering problems, such as influence of the terrain type on the flow over the wind turbines. All computational results will be compared with available wind-tunnel measurements.

### Expected scientific contribution

The given computational model represents novelty since neutral atmospheric conditions are achieved by implementing a new source term in the momentum equation. Such approach will allow the use of standard RANS turbulence models without altering the turbulence model equations. Thus one can use standard turbulence models which accuracy and generality have already been proven.

### Acknowledgments

The research is supported by the Croatian Science Foundation.

### Keywords

homogeneous atmospheric boundary layer, computational wind engineering, RANS turbulence modelling

# Biochemomechanical Finite Element Model of Abdominal Aortic Aneurysm Growth

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## Introduction

Abdominal aortic aneurysm (AAA) is a local and irreversible dilatation of infrarenal abdominal aorta caused primarily by an imbalance in production and degradation of the extracellular matrix. AAA is the most common type of aneurysms; it affects 3-9 % of men older than 50 years. It is an asymptomatic disease until complications, which can lead to rupture, occur. The only treatment is surgery, which is recommended based on the maximum diameter and growth rate (when available). AAA size was shown to be a quite unreliable criterion. Numerical models could expand our knowledge and understanding of this disease, and help in making the decision about surgery.

The majority of AAAs harbor intraluminal thrombus (ILT), which is a 3D fibrin structure comprised of blood cell, platelets, blood proteins and cellular debris adhered to the aortic wall. Studies have shown that ILT has a biochemical and mechanical influence on aneurysmal aorta wall. Despite that, most of the growth and remodeling (G&R) models of AAA, neglect ILT influence and focus only on the aortic wall.

## Aims

The aim of this work is to develop a 3D finite element growth and remodeling model of thrombus-laden AAA from the moment of initiation. In the first stage, the model will be limited to fusiform (axisymmetric) aneurysm, and later it will be expanded to saccular (asymmetric) aneurysm. The model will be used to test different hypothesis on AAA rupture and stabilization, and to investigate rupture risk factors proposed both by other researchers and by our group.

## Methods

Growth and remodeling model of aortic wall is implemented in finite element code, whereas the ILT model with its biochemomechanical influences is yet to be implemented. Models are

based on the constrained mixture theory and the theory of evolving configuration. Former means that constituents (e.g. for aorta: elastin, collagen and smooth muscle cell) are bound together and have the same displacement, while each of them can possess different stress state. Latter means that, in the present moment, the mixture is comprised of constituents created at different times in the past and each of them can have different deformation gradient. In finite element model of AAA, new additional elements, representing ILT, will be added based on the results from hemodynamics CFD analysis.

## Expected scientific contribution

A 3D finite element model of AAA with included biochemical and mechanical influence of ILT has not been developed yet. The model will enable more detailed AAA analyzes and it will broaden our understanding of AAA development and progression, as well as ILT influence on AAA growth. Additionally, the model will assess different proposed rupture risk factors. In the future, it could assist surgeons in making decision whether to perform surgery or not.

## Acknowledgments

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## Keywords

Abdominal aortic aneurysm, Intraluminal thrombus, Finite element method, Hemodynamics

# Hourly Based Multi-Objective Optimization of a District Heating and Cooling System with a One-Year Time Horizon

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## Introduction

District heating systems are a well-known technology which is used almost in every country in European Union. They can be effectively used to increase energy efficiency by using waste heat, decrease greenhouse gas emissions and integrate low-temperature renewable energy sources such as solar thermal and geothermal. Although district heating has additional benefits in comparison with individual heating systems, such as economy of scale and scope, their full potential in most of the countries still hasn't been fulfilled. Future energy systems will have a large share of electrical energy production coming from intermittent renewable energy sources and their integration won't be possible without district heating systems. An excess electrical energy could be efficiently stored in a form of thermal energy by using heat pumps and electrical heaters. To make future systems even more efficient and sustainable, integration of heating, cooling, gas and electric grids is needed. This idea is known in the literature as 4<sup>th</sup> generation of district heating. Due to high level of interconnection of masses and energy streams in these systems, their optimization represents a challenge for energy planners.

## Aims

The aim of this research is to develop a model which will be capable to optimize district heating and cooling systems in the most feasible way, which means economically acceptable and environmentally friendly. The model will have to optimize supply capacities as well as the operation of many possible technologies: cogeneration plant, heat only boiler, compression and absorption heat pumps, solar thermal collectors, including thermal storage. In order to capture specific energy planning issues, the optimization should be hourly-based with a one-year time horizon.

## Methods

Finding the solution of a multi-objective optimization problem sometimes presents a challenge. In the literature, many approaches were used which involve: least-squares method, iterative optimization techniques, mixed-integer linear and non-linear programming, genetic algorithms, etc. Choosing an optimization approach will have a lot of influence on a complexity of a physical model of the system. For the purpose of this research, mixed-integer linear programming optimization will be used. It is important to note that a multi-objective optimization doesn't have just one solution. In this case, the system can't be optimized in the same time both economically and environmentally. The result is a whole front of solutions which is called Pareto front.

## Expected scientific contribution

Contribution will be in the field energy planning and energy system optimization. According to the conducted literature review, there is a large number of papers dealing with optimization of district heating and cooling systems. They rarely study integration of heating and cooling sector and this many technologies on time scale of one hour for the whole year. Also, different temperature levels in the thermal grid are usually neglected. This research will make a detailed insight into the multi-objective optimization of integration of heating and cooling sectors on an hourly basis for the whole year.

## Acknowledgments

Financial support from the Croatian Science Foundation project RESFlex (PKP-06-2016) and European Union's Horizon2020 project PLAN-HEAT (grant agreement 723757).

## Keywords

District heating and cooling, multi-objective optimization, thermal storage, energy planning, renewable energy sources



# The Spatial Evaluation of Excess Heat Utilization in District Heating Systems

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## Introduction

District heating plays a key role in achieving high primary energy savings and the reduction of the overall environmental impact of the heating and cooling sector, which has been recognized as the most energy intensive sector in the European Union. Therefore, the European Commission started emphasizing the importance of these systems, especially when integrated with renewable energy sources, like solar, biomass, geothermal, etc. On the other hand, one of the most energy inefficient sectors in the European Union is industry, due to the significant amounts of heat that is currently being wasted. This excess heat can be utilized and transported to the final customer by a district heating network. Nevertheless, there is one significant barrier to its utilization. A large number of industries and other sources are located far from the potential customers and the areas of high heat demand densities. For this reason, it is necessary to make a detailed analysis of the potential exploitation of excess heat, taking into account both the technical and economic aspects.

## Aims

The aim of this study is to evaluate the economic feasibility of the excess heat utilization, depending on the distance of the potential excess heat source from the heat demand in the given area.

## Methods

A method will be elaborated in this work, in order to determine the technically and economically optimal solution for the coverage of the heat demand of a certain area. A multi-objective optimization will be used for this purpose. The focus will be on excess heat, taking into consideration its distance from the demand. It will be compared with local renewable energy sources as a part of the district heating network. Nevertheless, the method will also consider individual gas systems, which are currently the mostly

used heating systems in Europe. Optimization approach used in this research will be mixed integer linear programming.

## Expected scientific contribution

By making a detailed literature review in the area of excess heat utilization, it has been shown that, even though a lot of researches analyze the potential of its utilization and economic feasibility, practically no papers have provided the analyses of the spatial distribution of the optimal solutions with the focus on excess heat. Furthermore, only the utilization in the already existing district heating systems is analyzed. Therefore, this paper will analyze optimal configuration of the potential new district heating system using excess heat, depending on the distance from the heat source to the heat sink. The analyses will be done on an hourly basis.

## Acknowledgments

Financial supports from Croatian Science Foundation project RESFlex (PKP-06-2016) and European Union's Horizon2020 project CoolHeating (grant agreement 691679) are gratefully acknowledged.

## Keywords

Excess heat, district heating, renewable energy sources, energy planning, multi-objective optimization

## Reinforced Aluminium Foams

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### Introduction

Foamed materials in general, and aluminium foams in particular, demonstrate a number of interesting properties due to their porous structure, which makes them usable in a wide range of applications. Recently, foamed aluminium is frequently used in various absorbers of kinetic energy. The use of aluminium foams together with dense materials, such as sheets, tubes or more complex hollow shaped structures is interesting in the field of lightweight structural applications. The foamed panels can be reinforced by metallic wires or nets like a concrete. Problems in the production and application of metal foams arise from incomplete mastery of the process parameters, so often uneven and unpredictable structures and variations in property values are obtained. For foam with closed cells, due to the existence of the outer crust, the internal structure of the metal foam or the size, shape and distribution of the cells is not visible.

### Aims

One of the objectives of the study is to determine how the relative density of aluminum foam, the type and arrangement of reinforcement, and the shape of the sample reinforced aluminum foam, affect the homogeneity of the aluminum foam structure. Recently, there is a computer tomography device installed at the FMENA, and one of the goals is to prove that the homogeneity of the aluminum foam structure can be determined by this method. This will allow testing the mechanical properties of aluminum foams on the same samples previously analyzed. The research will determine the energy absorption of various aluminum foam samples and the aim is to show how the absorption of energy affects the type of wall material, the relative density and shape of the reinforced aluminum foam sample.

### Methods

The methodology for implementing the planned experimental research involves the activities

of selecting starting material, dimension and shapes of reinforced aluminum foam samples. After choosing optimal parameters for reinforced aluminium foam, next step is mold design for molding aluminum foam samples which will be used for production of aluminum foam samples. After obtaining suitable sampling, analysis of the homogeneity of the aluminum foam structure and the size and shape of the cell will be performed on a computer tomography device. After scanning the samples, energy absorption tests will be performed and analysis of the influence of certain input parameters on the final properties. By comparing the results of the test of homogeneity of structure and absorption of energy, it will be analyzed how the input parameters are influenced by them. In addition, the impact of the structure's homogeneity on absorption of energy will be analyzed.

### Expected scientific contribution

The results of this study should show how the properties of metal foam vary by varying the parameters during production and adding different strengths, and for the first time in aluminium foam research at the FMENA, possibility to see the inner material of metal foam and apply the same sample to the energy absorption test.

### Keywords

aluminium foam, absorption of energy, computed tomography

# Wire and ARC Additive Manufacturing of Duplex Stainless Steel Components

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## Introduction

Additive layer manufacturing has become an important industrial technology for manufacturing custom-made metal workpieces. Wire and arc additive manufacturing (WAAM), as one of the additive manufacturing technologies, has been gaining the interest of the research community due to its high productivity and excellent mechanical properties of the final product. WAAM is a process in which metallic components are built by depositing beads of weld metal in a layer by layer fashion. It can be applied to a variety of materials that can be welded, such as steels, Al alloys, Ni alloys and Ti alloys. Also, WAAM offers a potential approach to manufacture duplex stainless steel components with low cost and high efficiency.

## Aims

WAAM enables significant savings in the form of reduction in metal waste, reduced lead time and elimination of tooling cost. That is the most evident in case of expensive materials such as duplex stainless steel. The aim of this research is to define proper welding technology that will enable WAAM with duplex stainless steel. Optimal welding technology with carefully determined parameters will result with rapid manufactured component with favourable mechanical properties.

## Methods

Methods used in the research will be theoretical, numerical and experimental. Theoretical part will be the research of the optimal welding technology that will result with desirable material properties. The welding technology will be examined and verified through series of experiments. Influence of heat input, metal transfer and shielding gas will be tested. Evaluation of input variables will be performed through measuring distortion and testing of microstructure, mechanical properties and corrosion resistance.

In order to reduce number of experiments, numerical analysis of welding process will be used.

## Expected scientific contribution

The research will significantly contribute to the adoption of new materials in the field of WAAM. It will enable fast and low cost production of duplex stainless steel components with complex geometry. Also, the research will lead to conclusions of usability of wire and arc added manufactured duplex stainless steel components through their mechanical properties and corrosion resistance. Results will significantly play a part in the development and application of wire and arc added manufacturing.

## Keywords

duplex stainless steel, WAAM, welding

# The Sizing and Scheduling of Advanced Energy Systems Considering Demand Reduction and Energy Storage

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## Introduction

The new generations of district heating systems, and their ability to utilize RES (renewable energy resources) such as solar and geothermal energy, industrial waste heat, biomass, cogeneration, three-generation and poly-generation units, and power to heat technologies such as heat pumps and electric heaters, are crucial for the development of technologically advanced and cost-effective future energy systems as a whole.

## Aims

The aim of this work focuses on development and demonstration of an optimization model capable of handling both the sizing and the scheduling of new district heating systems, based on a heat only boiler, solar thermal collectors, electric heaters, heat pumps and thermal energy storage units while considering heat demand reduction through thermal insulation of old inefficient buildings. The model has been implemented on several different scenarios, representing two different neighborhoods located either inside a large city or in a small rural area.

## Methods

In order to enable full utilization of their benefits, the sizing and scheduling of mentioned systems needs to be optimized from an economic point of view simultaneously taking into account environmental impacts such as greenhouse gas emissions and air pollution. This is a computationally difficult task due to a large number of parameters that need to be calculated simultaneously. In order to tackle this issue a superstructure consisting of three modules has been developed. In the first module, an MILP (Mixed integer linear programming) optimization with a larger time step (several hours or days) is performed for the entire optimization horizon. In this step, the possible solutions are narrowed down by ignoring tight constraints such as unit commitment, ramp up and ramp down con-

straints, hourly temperature variations and electricity prices. The results from the first module are then passed in to the second module as upper or lower bounds. Here LP (Linear programming) optimization is carried out and final capacities of all available technologies are determined. The third module finally takes into account the tight constraints and performs MILP optimization to solve unit commitment of all components in the system.

## Expected scientific contribution

The described methodology is the first step towards creation of a new energy planning model capable of taking both the short and the long term constraints into account. This is especially important when impact of integration of RES combined with energy storage is to be analysed. The preliminary results have already demonstrated the economic and environmental benefits of the utilization of highly efficient and RES powered technologies combined with a seasonal or intraday thermal energy storage in the proposed system configuration. Furthermore, the potential of the heat demand reduction due to the refurbishment of old, uninsulated and thermally inefficient buildings has been analysed. The results have shown that such demand reduction can greatly influence the optimal mix and sizing of available technologies.

## Acknowledgments

Financial support from the European Union's Horizon2020 project CoolHeating (grant agreement 691679) and the 4DH project funded by the Innovation Fund Denmark as well as the financial support from the Croatian Science Foundation in the form of HRZZ project are gratefully acknowledged.

## Keywords

District heating, Thermal storage, Building refurbishment, Energy planning

# Vehicle Exhaust System Tempering Detection at Periodic Technical Inspection

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## Introduction

One of prerequisites for vehicle registration in most EU countries is a positive Roadworthiness certificate. Vehicles are inspected and checked for deficiencies, environmental or technical, at the periodic technical inspection (PTI). The goal is to keep the roads safe and ensure that vehicles don't pollute more than needed. Deficiencies in vehicles propelled by diesel engines, found in the exhaust system, can be costly to repair. Diesel particle filter (DPF) is the most expensive part in the exhaust system which is the main reason vehicle owners opt for its removal instead of buying a new one once it's determined to be faulty. The removal of DPF causes a significant increase in particle matter emissions from vehicles. At this moment, there are no simple none destructive test (NDT) methods of detecting DPF tampering.

## Aims

The aim is to find a fast, simple and cost effective method for detecting exhaust system tempering mainly focused on the DPF and later on expand the method to the exhaust gas return valve (EGR) and Diesel exhaust fluid system (AdBlue) during PTI.

## Methods

The research is conducted using various NDT methods, mainly thermography as a tool to gather exhaust systems isolation temperature values. Gathered data will show the thermal changes that happen at idle for vehicles equipped with a DPF and for vehicles with tampered DPF. That data could then be used to determine tempering and overall exhaust system health.

## Expected scientific contribution

Expected scientific contribution is a development of a new procedure for determining faults on vehicle exhaust systems which could then be translated to other exhaust systems. Those other

systems include ship engines, burners in factories and all other systems which have exhaust gas aftertreatment systems.

## Acknowledgments

I would like to thank to CVH for funding tools and helping me get vehicle dana needed to conduct the research and FSB for providing me with the necessary literature.

## Keywords

DPF tempering, thermography, vehicle emissions

## Development of a Model for Monitoring Efficiency of Human Resources in Periodical Technical Inspection Stations

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### Introduction

The digitalization of processes is surely becoming a requirement for successful organizations within different types of industries, above all to remain competitive. Digitized processes have more advantage, so that information is processed in a faster way and the final result is more precise, more accurate and more reliable results. In recent years, the emphasis is on knowledge that is based on data stored in the database, using Data Mining techniques that offer quick relationship finding between variables. Proper use of Data Mining techniques involves definition of the data volume, attributes and formats. Therefore, it is obvious that digitalization and modernization of organizations can result with cost reduction, increased productivity and time reduction. In addition to the mentioned, modern technologies are changing organizations and enterprises in various sectors. The concept of Industry 4.0 represents a development that is alternating traditional industries. Although the notion of digitization is closely related to the manufacturing industry, usage of new software models and wireless connection between devices and software is not important only for machine managing, but also could be significant for business processes managing and employee allocation. The latter is especially important because the most important factor in every organization and company is the human resource. Each employee performs work on his own way, although there are precisely specified directions. Therefore, it is important to find a solution or method which would significantly facilitate the management of employees in accordance with their capabilities and data on the efficiency of their work in real time.

### Aims

The aim of this research is to develop a model for monitoring work efficiency of employees in periodical technical inspection stations. The use of the model would provide greater transparen-

cy and decision making in a real time based on the processed data that are being stored in the database. It would provide quality decisions by displaying graphical and numerical data of the employee performance through a certain period, considering the average reference value.

### Methods

In order to provide digitalization, the lean concept application should be applied first through action research to enable waste identification and elimination in the process. The expected application model would use adequate methods of data analysis, data optimization and data mining in the context of business intelligence for creating a mathematical model for evaluating and comparing results. Therefore, other types of algorithm should be considered rather than a conventional one, mostly due to loss of its accuracy by time.

### Expected scientific contribution

This research could significantly contribute to the science, business and provide quality decisions that are accurate, complete and in real time. Also, it could be applied not only in the context of human resources, but in another area where is the need for decision making. Furthermore, this model would allow even non-experts to make quick and effective decisions in various industries. Finally, the developed model would eliminate autonomy and subjectivity in decision making processes.

### Acknowledgments

I would like to thank CVH (The Vehicle Center of Croatia) company that is supporting and providing this research.

### Keywords

Data analysis, Business intelligence, Industry 4.0, Lean concept, Human resources, Expert Systems

# Risk Management Modeling for Increase the Reliability of Maintenances Complex Systems

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## Introduction

Process equipment and plant maintenance problems are complex in their nature in oil refinery, since the effective maintenance needs to ensure reliability and availability of the plant. Failure Mode and Effects Analysis (FMEA) is method that is used in reliability and safety evaluations of complex systems to determine the effects of component failures on the system operation. This risk analysis tool assumes a failure mode, which occurs in a system/component through some failure mechanism; the effect of this failure is then evaluated. A risk ranking is produced in order to prioritize the attention for each of the failure modes identified. The method utilizes the risk priority number (RPN) ranking system. This method determines the RPN by finding the multiplication of factor scores. The three factors considered are probability of severity (S), occurrence (O) and detectability (D). Traditional FMEA has been criticized to have several drawbacks. These drawbacks are addressed in this research beyond complete FMEA project implementation in a few refineries in region.

## Aims

In order to boost Operational Availability and reduce dramatically Unplanned Shut Downs of Refineries, it is crucial to identify the root causes of actual events and tackle them with preventive and mitigating barriers. FMEA as one of the most relevant systematic techniques for failure analysis is used to identify and prioritize risk. Then mitigate risk based on either failure mode effect severity reduction or lowering the probability of failure or drawing operator's attention to missing detection installations. An integrity maintenance management system should be set up by identifying business critical systems and the risk of their failure. Then, determining risk mitigation actions and list of critical equipment.

## Methods

Research will be based on experimental data collected within ongoing pilot project of FEMA in refineries. The execution of an FMEA is carried out in interdisciplinary groups, the FMEA teams consists of a moderator, who offers methodical knowledge, and the FMEA team, which offers technical knowledge concerning the process or equipment to be analyzed. It is expected that the comprehensive exploration will lead to eliminate influence the decision factors which are relayed on knowledge and experience of refinery's experts. In order of the improvement of the traditional FMEA method, to resolve these drawbacks it will be proposed a new model that will include Fuzzy logic, AHP method, neural network and genetic algorithms. On the basis of these data, the model will be validated, and further used for second iteration of FEMA analyses.

## Expected scientific contribution

Although successful application of the traditional FMEA method and there have been observable improvements, it still suffers from several drawbacks. It is expected that this research would improve FEMA analysis for refinery application by answering these and many other research questions. The model for assessing the credibility of risk factors should be developed. Also, the model could help in order to standardized of procedure and make it friendly use, than mitigate the impact of the subjective assessment of the critical decisions. Therefore elaboration of the model for resolving the set problems, presents real scientific contribution for dealing with this kind of practical FEMA implementation disadvantage.

## Keywords

FMEA, risk management, availability, reliability, critical equipment





## **FINAL PHD TOPICS**



## Selective Algebraic Multigrid for Block-Matrices

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### Introduction

Discretisation of partial differential equations (PDEs) in the framework of the Finite Volume Method (FVM) typically produces very large sparse matrices with a small number of nonzero entries. The value of the solution depends on the values in the neighbouring cells. Depending on the treatment of the neighbours' values, explicit and implicit methods are distinguished. Most recent algorithms employ implicit methods in which all equations are solved simultaneously in a single block matrix. Choice of an appropriate linear solver is strongly related to the discretisation method, i.e. matrix properties. Most linear solvers have the optimal performance for certain types of matrices: diagonally dominant, symmetric and positive-definite. In this abstract, a newly implemented algebraic multigrid method will be presented. The method is based on the classical multigrid coarsening algorithm (SAMG) and works for both scalar and block matrices.

### Methods

Simple iterative solvers such as Jacobi and Gauss-Seidel operate in a point-by-point manner and incrementally improve the solution. Thus, in an N-dimensional space of an N by N matrix, fixed-point methods visit each direction of the N-dimensional space separately. On the other hand, Krylov subspace methods, such as Generalised Minimal Residual (GMRES) and Conjugate Gradient (CG) methods and its variants, choose the solution direction by evaluating the residual and searching for its smallest components. These methods are fairly efficient when combined with matrix preconditioning. The most powerful class of iterative linear solvers are the multigrid methods, which exploit the fact that beforementioned point-fixed methods tend to quickly reduce the high frequency solution errors, i.e. the errors whose direction corresponds to the largest eigenvalues of the matrix. However, the low frequency errors remain and

this is why the performance (convergence) of the fixed-point methods deteriorates. To solve this issue, multigrid methods construct a hierarchy of grids by coarsening the initial grid. The low frequency errors on the finer grid become high frequency errors on the coarser grid and the fixed-point algorithms are able to efficiently reduce these errors. The correction obtained on the coarser grid is then transferred back to the finer grid. Algebraic multigrid methods operate on matrix coefficients directly and do not need a computational grid.

### Preliminary results

The implemented algebraic multigrid algorithm (SAMG) was compared to a simplified algorithm based on agglomeration of equations into clusters (AAMG). AAMG is currently the most used multigrid solver due to simple implementation and computational efficiency. However, first results show that more accurate interpolation operator assembled in SAMG provides better convergence (less iterations) both for scalar and block matrices.

### Discussion

Selective algebraic multigrid (SAMG) converges faster than aggregative-based algebraic multigrid (AAMG) and the advantage is more obvious with a tight convergence tolerance. One iteration of SAMG is computationally more expensive than one iteration of AAMG. It is possible to optimise SAMG's setup phase to reduce the computational time. SAMG increases the diagonal dominance of the block-coupled matrix on coarser levels and makes point-fixed smoothers more effective.

### Keywords

algebraic multigrid, block-coupled solver, linear solver

# Data Preparation for Modelling of Energy Consumption in District Heating Systems Based on Machine Learning

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## Introduction

The building sector in the EU spends about 32 % of the total final energy is consumed for heating. Influential factors on the energy consumption can be defined as physical and non-physical, whereby the non-physical forms of consumption include climate, social and behavioural aspects, such as demographic factors, the daily schedule of the use of space and others. In targeting consumption reduction, the EU has set several measures in legal framework to help each of the member state in reaching these goals.

Previous analyses and models have predominantly taken into consideration only physical factors. In recent years, there is an extensive development of the Data science and Big Data sciences and the wider application of machine learning methods to the analysis of the various areas. One of the important steps before making analysis using machine learning is data preparation and pre-processing, that is described in this paper.

## Methods

The direct hypothesis is that the collected data is sufficiently representative and with appropriate pre-processing, that is by using descriptive multivariate statistical analysis and explorative analysis, it is possible to obtain a more detailed insight into the data character, their representativeness and their interrelationship (similarity, correlation, data group, distribution) and give an appropriate estimate of the benefits of installing into the predictive model.

Experimental research is conducted on a set of actual energy consumption data obtained from entities in the sector over a several-year period. All factors influencing consumption are defined in terms of physical and non-physical factors. Physical factors include insulation quality, number of floors, number of rooms, the existence of individual metering and types of measuring

devices, the degree of heating, etc. Non-physical factors include the number of tenants, the age of tenants, the method of calculation for the energy consumed and the energy price, the level of desired thermal comfort, etc.

A model is under development including these steps: pre-processing, sampling, prediction model based on the learning set, and testing the model on the test set. In this paper, descriptive multivariate statistical analysis and explorative analysis is used to perform the prepare the data for the analysis.

## Preliminary results

Preliminary results that are not considering the non-physical influential factors on heat consumption, that the introduction of individual metering in the district heating systems reaches energy savings on the level of 27 %.

## Discussion

Assessment of the energy savings based only on physical parameters is not giving the appropriate results. The behaviour of the tenants and other non-physical factors are recognized as the predominant influential factor on the energy consumption. The behavioural factors should be further accessed and attributed to the consumption and the level of savings after implementing energy efficiency measures in district heating systems.

## Keywords

district heating, energy efficiency, statistical analysis, data analysis, machine learning

# Multiscale Green Sea Loads Simulations in Irregular Waves with Naval Hydro Pack

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## Introduction

The aim of this study is to devise a comprehensive multiscale procedure for prediction of green water loads on naval structures. The multiscale procedure includes linear seakeeping methods as well as detailed CFD approach. The proposed procedure is a three-step process which correlates the stochastic nature of ocean waves describing the sea states which the object encounters, with deterministic highly nonlinear and transient loads caused by green sea events (water on deck).

## Methods

This study is based on the Finite Volume method in collocated arrangement Computational Fluid Dynamics (CFD). During the study, Naval Hydro pack is used and developed, which is based on CFD open source software foam-extend. Naval Hydro is specialized for two-phase, viscous, turbulent and transient flows encounter in naval hydrodynamics. It contains special tools for fast and robust naval hydrodynamics simulations, such as SWENSE solution decomposition method, Ghost Fluid Method for discretization of the free surface boundary conditions, linearized free surface model for simplified free surface simulations, providing a significant acceleration in CPU time, and many other methods. It is equipped with solid body motion algorithms which couple the fully nonlinear fluid flow and rigid six-degrees-of-freedom motion of a naval object.

In addition to Naval Hydro pack, linear seakeeping methods will be used to explore the possible encounter wave spectra to which the naval object will be exposed in service. Using linear seakeeping, probability of green sea event for a given sea state can be assessed. This provides the means to compare a large number of sea states in order to detect the most adverse sea state from the green sea occurrence point of

view. The hydrodynamic coefficients, however, are calculated using CFD.

## Preliminary results

First step in this study is to validate the Naval Hydro pack for assessing pressure loads in green water events. For this purpose, a detailed numerical study is performed for a simplified fixed FPSO (Floating Production, Storage and Offloading) vessel, where pressure on deck is measured on ten locations in regular incident waves. The pressure measured at the deck is compared to experimental results. Preliminary results show very good agreement and similar uncertainty ranges.

## Discussion

The next step in this study is to apply the proposed procedure on a example of a FPSO vessel. First, the hydrodynamic coefficients need to be assessed using CFD. Next, the linear seakeeping method will be applied to detect the most adverse sea state regarding green sea loads. Then, a three hour seakeeping CFD simulation will be performed by using SWENSE method in irregular waves, where water on deck will be monitored in order to detect green sea events. Among the green sea events, the worse case will be chosen, and it will be used in the final step. The final step is to preform a detailed CFD simulation where only a part of the ship will be simulated, in which detailed deck structures can be modelled.

## Acknowledgments

This research was sponsored by Bureau Veritas under the administration of Dr. Šime Malenica.

## Keywords

Green sea loads, CFD, seakeeping, irregular waves, Naval Hydro pack

## Adhesion of Pacvd Coatings on Nanostructured Hardmetals

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### Introduction

Metal cutting industry has scaled cutting tools microstructure to nano grain size due to improvements in hardness and fracture toughness values. According to SECO the usage of finer grain sized substrate also achieves superior resistance to crater wear and resists the tendency to develop a built-up edge, and so provides tripled tool life. Alongside to a small grain size, complex coating systems are being developed on the surface of a tool. If produced properly, coatings provide significant improvements in hardness, toughness, oxidation resistance, and so further improve the duration of a tool itself. Increasing the number of layers in multilayer coatings increases the elastic modulus, hardness and toughness with respect to the single-layer coatings. As opposed to single layer coatings, compressive residual stress that rises as the number of layers increase in the multilayer coatings prevents crack propagation. As a primary demand on a coated tool is the coating adhesion which decreases as the number of layers increase, this has become the limiting factor in application of complex coatings systems with higher thicknesses.

### Methods

Samples of nanostructured hardmetals were sintered as a substrate material by two processes; liquid phase sintering in hydrogen atmosphere and sinter-HIP. The starting powders had an average grain size dBET from 95 nm to 150 nm. PACVD coating process was used for the production of the coating, and two coating systems, 2  $\mu\text{m}$  TiN and 3,8  $\mu\text{m}$  TiN-TiCN were produced. In order to quantify the primary demand for a quality coating system, high coating adhesion, scratch tests were conducted by drawing a Rockwell C diamond stylus. Linear increasing load ranging from 5 to 200 N, was applied across the sample surface, and critical loads of coating delamination were registered.

### Preliminary results

Coating thickness while comparing TiN and TiN-TiCN coating had a low influence on the coating adhesion. In some cases, a complex architecture multilayer coating has shown better adhesion to different substrate materials because of the mentioned compressive residual stress which occurs in this coating types. This increases the critical load force of a coating spallation. According to the research in progress, the PACVD coatings on various nanostructured hardmetals can have an excellent coating adhesion ranging up to 198 N.

### Discussion

This is just a first in a line of tribological testing with the purpose of producing a fully functional nanostructured PACVD coated WC-Co cutting tool, and for that reason, two sintering processes, two coating systems and different coating thicknesses were produced. Difference in microstructure and coating type among samples make it difficult to give firm conclusions on the exact factor that gave the specific coating adhesion, but give an overview on the basic material / coating system behavior.

### Acknowledgments

The research was funded by the Laboratory for Testing Mechanical Properties HMI/FSB-LIMS.

### Keywords

hardmetals, PACVD, scratch resistance, coating adhesion

## Socio-Economic Aspects of Different Cogeneration Technologies in Market Environment

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**Mentor/s:** Dražen Lončar

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### Introduction

Energy sector nowadays faces many challenges which are often not complementary. Incentives of the European Commission regarding the reduction of negative CO<sub>2</sub> impact on global climate change is one of the most significant mechanism which implies deployment of new technologies as well as new approaches in energy system. Contemporary and future energy markets are more dynamic and conventional power plants, as well as cogeneration plants will have to adapt new approaches and operation strategies in order to maintain their market share.

### Methods

In this paper the investigation have been made how different generation plants can satisfy heat demands and at the same time minimise operation costs, CO<sub>2</sub> emission and consumption of primary energy. In that sense, hierarchical optimization procedure was carried out which enables application of different criteria, i.e. it was possible to set different goal functions. Special attention was put on the CO<sub>2</sub> emissions. In order to quantify the social impact of different generation plants CO<sub>2</sub> emission cost was analysed in different scenarios. Moreover, economic analyses were based not only on operation expenditures but also on the capital investments. Different technologies were analysed, biomass based cogenerations, fossil fuel based cogenerations (in combination with gas engine and gas turbine), heat pumps, electric boilers and fossil fuel boilers. In order to determine optimal generation set-up simulation was.

### Preliminary results

Results of three-criteria optimization procedures indicate that heat pump is technology which should be further, more detailed evaluated, especially if compared with conventional generation technologies, such as gas turbine and gas engine. Heat pump generated approx. 50 % of

heat and thus reduced the number of operational hours of gas based cogeneration technologies. On the other hand, biomass based cogeneration technologies shown significant reduction in costs compared to gas based cogeneration technologies. However, the drawbacks of biomass are its availability and thus there stays the question is it always possible to utilise biomass in large scale plants.

### Discussion

However, here is necessary to emphasize the fact that within this research benefits of gas engines and gas turbines, as a flexible generation technologies which can participate in power system stabilisation are neglected, i.e. they are neither economically nor technically evaluated. The mentioned benefits, such as possibilities to provide flexibility, i.e. ancillary services to the power system, and evaluation of them is something that will we further addressed in the future research and what will give clearer picture of the most convenient choice of the heat and electricity generation technology in the future, dynamic energy system.

### Acknowledgments

Authors would like to express their gratitude to Mr. Krešimir Komljenović, manager of the EL-TO power plant at HEP – Croatian national power utility company who put at disposal operational data which were essential for deployment of the optimisation procedure.

### Keywords

social impact, CO<sub>2</sub> emission, techno-economic analysis, multi-criteria optimization

## Selection Model of Lean Tools at Company Restructuring Process

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### Introduction

Lean methodology has become industrial "standard" in developed societies. This methodology gives every organisation chance for continuous improvement in order to enhance overall business solvency and profitability. There are twenty five lean tools that provides lean transition, but every tool has its purpose and time of implementation. Implementation of basic lean tools during restructuring process can be hard and complex job because sequence order has to be in time and right. Each tool has its time and purpose of implementation. Sequential order of lean tools implementation has to be perfect if we want fast and efficient transition into lean organisation.

### Methods

Good lean transition should be based on proactive, fast and simple decision making principals. Restructuring process of every organisation is long term goal that is driven by enthusiasm of all employees. If there is no positive continuous improvement culture, than transition into lean will be far more difficult and complex. First step of lean implementation has to be focused on creating positive lean culture and putting metric into overall business processes and activities. In next steps organisations should implement lean tools that are most suitable for enhancing effectiveness and optimization of all activities. Basic goal of lean organisations is continuous improvement. This statements are result of study made by accumulation of all key datas about lean implementation in Croatian companies.

### Preliminary results

Continuous improvement is state of the art principal in lean methodology that provides long term stability on competitive markets. This continuous improvement has to be accompanied by adequate lean tools such as: 5s, Andon, "Bottleneck analysis", "Continious flow", Gemba, Heijunka, Hoshin Kanri, Jidoka, JIT, Kaizen, Kan-

ban, KPI, Muda, OEE, PDCA, Poka-Yoke, "Root cause analysis", SMED, "Six big losses", Smart goals, "Standardized work", "Takt time", TPM, VSM and "Visual factory. This twenty five lean tools provides essential steps for lean transition and creation of positive working culture. This study will show best practices of lean transition and pinpoint crucial lean tools for each step of lean methodology implementation process. As well it will be represented how bad lean transitions are made where adverse working culture will be pinpointed.

### Discussion

Basic lean tools provides essential steps for lean transition and creation of positive working culture. This study will show best practices of lean transition and pinpoint crucial lean tools for each step of lean methodology implementation process. As well it will be represented how bad lean transitions are made where adverse working culture will be pinpointed.

### Keywords

lean implementation, lean tools, continuous transition



# A Meshless Framework for Marine Hydrodynamics

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## Introduction

The lifetime of a ship or other floating body is characterised by vigorous interaction of its semi-immersed hull and surrounding fluid. An insight into the fluid-structure interaction is needed within each stage of the design process of a ship, in order to yield a reliable final design that will satisfy safety and other requirements. Inadequate methods are often reached for when calculating the input needed to solve a problem under consideration. Empirical methods based on statistically analysed finite amount of data can be fast, but inaccurate. On the contrary, classical Computational Fluid Dynamics (CFD) methods are accurate, but can be too slow for preliminary stages of the design process. Besides the CFD simulation process, creation of topologically and geometrically correct mesh is time consuming work and often requires user interventions in mesh generation steps. In this work, a truly mesh-free implementation of a CFD solver is introduced, which requires minimum user intervention effort for the simulation setup and yields satisfactory flow simulation.

## Methods

A novel meshless approach to approximating spatial derivatives on scattered point arrangements is derived using the Taylor series expansion and renormalised least-squares correction of the first derivatives. The introduced spatial operators have compact support, and are used to represent discrete Navier-Stokes equations in strong formulation. Unsteady single-fluid flow is solved with the velocity-correction projection scheme. The numerical solver is implemented using GPU and CPU parallel algorithms, and the simulation geometry is set up without any requirement for the volumetric mesh generation, since the boundary conditions are imposed in the immersed-boundary manner.

## Preliminary results

In order to validate the method for violent and free-surface flow, two validation tests were simulated: water entry of a wedge-shaped section, and water entry of a cylindrical-shaped section. Numerically obtained results of the pressure field and free surface kinematics during the water entry were compared with the experimental data from the literature. A good agreement was achieved, i.e. the pressure field and free surface evolution during the slamming were well-reproduced.

## Discussion

In addition to the validation of the method for the evaluation of slamming loads, future work will include the validation for other violent fluid-structure interaction problems with a fragmented free surface, such as the sloshing in tanks, green water on ship deck, etc. Moreover, the straightforward imposition of boundary conditions offers the possibility of domain partitioning by coupling the introduced solver with other solvers.

## Acknowledgments

I wish to thank prof. Degiuli and prof. Ban for their constant encouragement and support.

## Keywords

CFD, meshless method, Navier-Stokes, marine hydrodynamics

## Aerodynamic and Aeroelastic Characteristics of Cable-Supported Bridges with Roadway Wind Barriers

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### Introduction

Strong cross-winds that commonly blow on bridges and viaducts are observed to cause dynamic instabilities for passing vehicles, which may overturn or collide with other vehicles. Hence, wind barriers are developed to protect vehicles from cross-wind effects. While these barriers proved to be successful in sheltering vehicles on bridges, their influence on bridge dynamic stability is not well known. Long-span cable-supported bridges are flexible structures susceptible to self-excited oscillations, such as flutter or galloping. Thus, experimental research on influence of wind barriers on aerodynamic and aeroelastic characteristics of three different types of bridge-deck sections is carried out in collaboration with the Institute of Theoretical and Applied Mechanics in Prague (ITAM). Wind-tunnel models of bridge sections are studied for various wind barrier height and porosity using the experimental mechanisms for advanced aeroelastic and aerodynamic tests.

### Methods

Experiments are carried out in the climatic boundary-layer wind tunnel of the ITAM. During the experiments on bridge-deck dynamic response, the bridge-deck models are placed on the custom-made mechanism for measurements of complex aeroelastic phenomena. This mechanism is designed to allow for large generalized dynamic deflections with a linear behavior in the heave and pitch motions. Aerodynamic force and moment coefficients are determined using the custom-designed mechanism that allows for measuring aerodynamic lift and drag forces and the pitch moment. Flow characteristics downwind from the bridge-deck models are measured using the CTA (Constant Temperature Anemometer) device. Flow field around the bridge-deck section models is obtained using the PIV (Particle Image Velocimetry) technique.

### Preliminary results

The wind barriers prove to considerably influence the aerodynamic loads of bridge-deck sections, that is more exhibited for low-porous and high wind barriers. The wind barriers prove not to induce the galloping instability that is based on the results of the Glauert – Den Hartog criterion. Flutter stability of studied bridge-decks is deteriorated, while the critical flutter wind velocity is reduced when wind barriers are placed on bridge decks. The eigenvalue analysis indicates a significant decrease in the critical flow velocity for flutter when the wind barriers are in place. The influence of the wind barriers is larger for low-porous wind barriers, while the influence of the wind barrier height depends on the shape of the bridge-deck section.

### Discussion

The experimental results indicate an exhibited influence of porosity and height of the wind barriers on aerodynamic and aeroelastic characteristics of studied bridge-deck sections. Wind barriers present an additional obstacle to the wind flow and create an increased flow pressure on the leading edge of bridge decks. Bridge decks with wind barriers experience negative aerodynamic damping in torsional motion at certain wind velocity, thus the net damping of the system (consisting of aerodynamic and mechanical damping) is reduced. Therefore, bridges with wind barriers could become dynamically unstable in torsional motion, thus indicating an adverse effect of wind barriers on torsional flutter.

### Acknowledgments

The research is supported by the Croatian Science Foundation.

### Keywords

Bridge deck, Wind-tunnel experiments, Wind barriers, Galloping, Flutter.

# Numerical Simulation of Lubricated Wire Rolling and Drawing

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## Introduction

Numerical method for calculating lubricated contact pressures, friction and heat transfer during the metal forming simulations is presented in this study. Parameters of contact between metal forming tool (e.g. roller) and workpiece (e.g. wire, sheet) are important factors in metal forming processes since non-optimal frictional effects can result in lower productivity of process machinery, and in unacceptable shape and surface quality of the products. In order to control friction and heat transfer during the metal forming processes lubricant is applied between the tool and workpiece surfaces in contact.

## Methods

Tool and workpiece surfaces, seemingly smooth, have a large number of micro-asperities which play a significant role in frictional contact effects, thus capturing interaction between the asperities, i.e. surface roughness, and lubricant flow inside surface contact is required in order to have a good representation of contact phenomena. During tool and workpiece interaction thickness of the lubricant film changes with the deformation of surface asperities. Depending on thickness of the film, lubricant flows in four characteristic local regimes: hydrodynamic (thick or thin), mixed and boundary regime. In order to calculate lubricant flow between two rough surfaces in contact the modified Reynolds equation is used. The modified Reynolds equation is a 2D partial differential pressure equation discretized using the Finite Area Method over a workpiece contact patch. In order to represent interaction between two rough surfaces in contact an asperity contact model is required. Several contact models were implemented: Greenwood-Williamson, Wadwalkar's and Peng's models. Wadwalkar's model is an elasto-plastic model derived using finite element simulations of spherical asperities. It is an extension to Jackson-Green model enabling large asperity deformations. Peng's model was

based on finite element simulations of spherical asperities on deformable substrate. All three implemented contact models can be used in statistical or deterministic rough surface framework. Statistical framework uses measured surface roughness to calculate average surface parameters (asperity radius, asperity density and surface roughness), while deterministic framework calculates contact areas and loads directly from measured roughness data. Previously described contact models are implemented as a solid contact boundary condition for a large strain hyperelastoplastic deformation solver implemented in foam-extend, a community driven fork of OpenFOAM.

## Preliminary results

Compressible form of modified Reynolds equation is able to tackle non-physical negative pressures in diverging parts of the contact, while incompressible form of the equation cannot. Wadwalkar's contact model gives better results, compared to FEM simulations of spherical asperity for larger deformations, than Jackson-Green and Peng's model. Wire rolling and drawing simulations will be performed and compared using different contact models.

## Discussion

Elasto-plastic contact models should give contact areas and forces which are more physical compared to elastic models (Greenwood-Williamson), in case of metal forming processes. Using compressible form of Reynolds equation enables limiting hydrodynamic pressure in diverging parts of the contact, which are important in wire rolling.

## Keywords

Lubricated Contact, Finite Area Method, Reynolds Lubrication Equation, Metal Forming, Fluid-Structure Interaction

## Protocol Analysis of Teamwork in Design

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### Introduction

Teams are the core building blocks of modern product development companies. Understanding teamwork is essential for both researchers and practitioners responsible for the formation of teams and allocation of project resources. Thus, the number of studies aiming at understanding how designers work in teams is continuously increasing.

To identify regularities in the phenomena of teamwork design, one must observe it at high levels of granularity and abstraction. Presented research is focused on recognising such patterns in team behaviour and correlating them to the team structure and context.

### Methods

Of all the varied range of methods for fine-grain investigation of design activity, protocol analysis has been regarded as the most suitable to reveal the cognitive activity of designers. Hence, the presented research is designed in the form of a protocol study.

Methodologically the study follows five steps: identification of available data (video recordings), development of a coding scheme, segmentation and coding of data, analysis of captured protocols, and discussion of the results. Two teams performing idea-generation in conceptual design phase were recorded. Team 1 consisted of three mechanical engineering students in laboratory environment, and Team 2 consisted of three experienced designers in real organizational environment. The coding scheme was developed to reflect elementary design operations of analysis, synthesis and evaluation (ASE) and the alternation of the problem-solution related discussion. The video recordings were segmented and coded with design operations.

### Preliminary results

The distribution of segmented codes shows that Team 1 spent more time formulating and analysing problems while Team 2 spent more time

generating, analysing and evaluating solutions. Both teams spent most of the discussion to synthesise and analyse, with evaluation being rarely performed. Additionally, transitions between the coded segments show that for the Team 1 78 % and Team 2 60 % of transitions followed three directions: synthesis to synthesis, synthesis to analysis and analysis to synthesis. In the problem and solution space the most dominant transitions for Team 1 were the cycles of problem formulation related discussion, while Team 2 had cycles of solution generation and analysis.

### Discussion

Protocol analysis of both teams revealed patterns of analysis, synthesis and evaluation in the problem and solution space. Proportions of design operation correspond to what has been reported for the brainstorming-driven idea-generation sessions in other studies. Both teams show dominant alternation of synthesis and analysis which is typical for idea-generation sessions. Such cycles are repeated until the current aspect of design entity evolves to a satisfactory level or the topic changes to another design entity aspect. Furthermore, as brainstorming method is perceived as a tool of creative design, the alternation of problem and solution related discussion supports the co-evolutionary models of designing.

### Acknowledgments

The abstract reports on work funded by the Croatian Science Foundation MInMED project ([www.minmed.org](http://www.minmed.org)).

### Keywords

design process, conceptual design, protocol analysis, teamwork, human behaviour in design

# High Temperature Latent Heat Storage Modelling and Validation

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## Introduction

Increasing power systems flexibility to allow greater penetration of renewable sources is one of energy transition priorities. Most significant flexibility improvements can be achieved through installation of large scale energy storages. While development of direct electric energy storages in form of large batteries advances rapidly, equal potential for some applications is found in large thermal storages, especially in case of concentrated solar power (CSP) plants. After long period of investments stagnation, huge increase in CSP installations can be observed, especially in Morocco, South Africa, China, United Arab Emirates etc. This renewed popularity is, in large part, result of very effective utilization of large energy storages in such plants. Although sensible heat storages are still dominant storage technology in CSP industry, latent storage has much greater potential and its implementation is only matter of successful mitigation of its disadvantages. Most popular phase change materials (PCM) used in high temperature latent heat storages (HTLHS) are different salts, popularly called "solar salts".

## Methods

To improve performances of HTLHS, namely heat rate during charging and discharging, it is necessary to improve heat conductivity of PCM. Scientific efforts to improve heat conductivity of high temperature PCM can be divided in two directions: improvement of physical properties by combination with different high conductivity materials and geometry modifications for higher heat transfer rates. No matter the approach, exact simulations of PCM behavior are necessary for further investigations in high temperature PCM and development of new storage designs.

In this work 2D and 3D numerical models based on enthalpy-porosity method introduced by Voller are developed. Models are further extended to incorporate conjugate heat transfer (CHT) and enable simulations of heat transfer

through heat exchanger material and storage medium (PCM).

PCM models are usually validated by shape and position of the phase-change front, however such data for most solar salts, including most popular,  $\text{NaNO}_3$  does not exist. Therefore, extensive experimental measurements for acquisition of front shape and position are planned.

## Preliminary results

Presented mathematical model is implemented in OpenFOAM, an open source CFD tool. First results provide very good agreement with existing experiments, but lack of experimental data limits validation options. Simulations of different shell and tube configurations with multiple tubes and different positioning shows that even small changes in geometry can lead to significantly different heat transfer rates over time.

## Discussion

Results can be further improved with implementation of temperature dependent material properties, unfortunately there are large discrepancies between results from different researchers, especially in case of thermal conductivity of solid  $\text{NaNO}_3$ . New experimental measurements should provide sufficient data for model validation.

## Keywords

High-temperature thermal energy storage, concentrated solar power, phase change materials, mathematical modelling, heat-exchange enhancement

# Numerical-Experimental Suitability Analysis of Using Agricultural Biomass in Hot Water Boilers

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## Introduction

Increasingly stringent environmental requirements of the EU require the development of new design solutions of the combustion system for residential hot water boilers fueled by some solid biomass. Emissions are becoming even greater problem if instead of wooden biomass various residues from agricultural production are used, which are becoming more desirable fuel due to their low cost. This work, by means numerical and experimental methods, aims to explore applicability of the agricultural biomass for combustion in the residential burning appliances and mechanisms of pollutants reduction. The goal is to achieve guidelines for design of commercial hot water boiler prototype.

## Methods

Information relevant to the combustion properties of agricultural biomass have to be researched via literature survey and laboratory testing. Based on that the appropriate residue will be selected. Selected biomass will serve as a fuel based on which guidelines for the construction of prototype of commercial hot water boiler will be developed. In order to meet all EU emission requirements key places for pollutant generation need to be identified. To do that, CFD model of the hot water boiler will be made. Following this, new design solutions for combustion system that avoids previously detected places, will be proposed and evaluated.

## Preliminary results

Low ash melting temperatures of most types of agricultural residues is identified as a crucial problem in achieving an efficient combustion. Rotary combustion chamber burners proved to be particularly suitable for burning of fuels with low ash melting temperatures without the need to manually remove agglomerate or slag. Other essential problems are high content of the volatile mater. This means that combustion

is expected to be rapid and difficult to control resulting in high amount of pollutants. For that reason, combustion chamber needs to be constructed in a manner that ensures complete combustion of the volatiles in order to ensure low emissions. This can be achieved by installing various obstacles to flue gas steam flow and insulating the whole combustion chamber. In theory, this solution can also ensure destruction of dioxins temperature in combustion zone. Other mechanisms of dioxin formation can be potentially controlled by porous ceramic media installed behind the combustion zone.

## Discussion

In literature, combustion properties of agricultural biomass are only explored in terms of applicability to burn in existing burning appliances. Ash melting temperatures are determined and increase in pollutant emission compared to wooden biomass is quantified. No data regarding dioxin emissions was found, although in Commission regulation (EU) 2015/1189 clearly states that appliances that use non-woody biomass may have significant amount. Also, there is no data that investigates the potential of certain modification to the combustion system to reduce the pollutant emission. New proposed modification should ensure cost-effective low emissions combustion system (and low dioxin emission) that meets EU requirements set for 2020.

## Keywords

low ash melting temperatures, dioxin emissions, agricultural biomass

## Two-Way Coupled Eulerian-Eulerian Simulations of Drifting Snow with Viscous Treatment of the Snow Phase

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### Introduction

The objective of this research is to present a two-way coupled two-fluid model, which models the snow phase as an Eulerian continuum, similarly to the air phase. Besides properly accounting for two-way coupling in the saltation layer, this model is free from all equilibrium assumptions used in other one-way coupled approaches based on the transport of snow density method or the volume of fluid method.

### Methods

The new model is implemented in the Finite Volume C++ CFD toolkit OpenFOAM. A purposely developed snow phase viscosity model for high rates of strain is used.

### Preliminary results

This new formulation is validated against detailed experimental measurements of snow flux and airflow velocity profiles, at several measurement stations along the working section of a controlled wind tunnel drifting snow experiment. When polydispersity of the snow particle phase is taken into account, good agreement is found between the simulation results of snow flux and airflow velocity profiles, and the experimental measurements. The standard k-epsilon model used was found to overestimate the turbulent kinetic energy compared to experimental measurements. However, the experimental measurements are believed to somewhat underpredict the actual experiment turbulent kinetic energy levels, as stated by the experiment authors.

### Discussion

The present novel approach is found to accurately predict snow flux and airflow velocity profiles. It is desirable to replace the k-epsilon model with the more robust and accurate k-omega SST. Moreover, polydispersity is presently simulated by combining the results of several monodisperse simulations. It is desirable to

implement polydispersity directly in the formulation instead.

### Acknowledgments

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All simulations were carried out on the Arctur-1 supercomputer, courtesy of ARCTUR d.o.o.

### Keywords

Drifting Snow, Eulerian, Multiphase, Viscosity, Gamma Distribution

## Model of Integrated System for Monitoring and Increasing Availability and Efficiency of Production Equipment

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### Introduction

The purpose of this paper was to introduce a model for monitoring of production time and downtimes with increasing the availability and efficiency of production equipment. Methods and tools for improving efficiency and usability of production equipment are proposed. The description of concept Internet of Things (IoT), total productive maintenance, overall equipment efficiency, and total effective equipment productivity is given, as well as guidelines on collecting the required data to achieve these initiatives. Calculations of OEE, as one of the key performance indicators of equipment effectiveness was also given and explained. Solutions and explanations for faster and more accurate collection of data were proposed. Categories of production losses were listed and explained describing how they affect the actions needed to be done in order to reduce production stoppages. Also, a model was proposed for reducing the performance category of losses in order to increase overall equipment efficiency.

### Methods

One of main focuses in the paper was calculating the Overall Equipment efficiency number. Overall equipment efficiency (OEE) looks at the potential production time as a maximum, without calculating time that has been unscheduled. It identifies the percentage of manufacturing time that is truly productive. In order to explain OEE the data collection and OEE analysis was conducted in the company Elektro-kontakt d.d. within a period of 24 hours split between 2 shifts. The measurement of downtimes occurred on the stamping machine for producing metal pieces from raw metal band. It is an example of real OEE analysis. In addition, in order to reduce performance losses, which affects OEE percentage, the integrated wireless paging model is proposed.

### Preliminary results

The proposed integrated pager system is in direct relationship with production equipment downtimes and efficiency measured by the OEE analysis. By implementing such a solution, better understanding and overview of production equipment is achieved. Workers responsible for the group of equipment have better understanding of the production equipment state in real time. Analysis can be done retroactively as well since all the stoppages are measured in the database and stored for further examination and data extraction. All of these systems proposed represent a move towards better business production model, and overall efficient way for keeping material input, product output and worker awareness at optimum levels.

### Discussion

This concept, in my opinion, stems from the ability to realize problems and concerns early and rectify them 'on-the-fly' rather than using ad hoc methods or time-consuming analyses after a minor or major stoppage of work. Companies that can make in-course corrections are more effective, and needless to say – more profitable, than companies who wait for catastrophic failures to occur before making changes to their management or manufacturing model. The threat of not meeting the required deadlines or fulfilling the required quota can be damaging. And this is exacerbated during times when manpower is at a minimum during vacation periods, holidays, illness, medical leave or what not. Just one or all of these conditions could have negative ramifications on the company's name or reputation, to say nothing of the morale of the workers involved. I believe that all of this can be prevented.

### Keywords

overall equipment efficiency, internet of things, production losses



# Numerical and Experimental Modeling of Anterior Cruciate Ligament Biomechanical Implant Support of Knee Joint

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## Introduction

Since human knee is used in all movements, damage of anterior cruciate ligament is very common. In recent years, the number of people who are exposed to anterior cruciate ligament injuries (ACL) is increasing. The ACL is one of four major knee ligaments which connects the back of the thigh bone with the front of the tibia and provides knee joint stability as well as limits rotation during movement. If there is a major damage of an ACL, in most cases, surgery is the only procedure to be undertaken for the patient's effective return to daily activities. Rehabilitation of an anterior cruciate ligament is very significant for regain the function of this body part in proper condition. Today's technology leads to the development of a range of solutions that enable better way of rehabilitation process during and after surgical procedure or after ACL injury.

## Methods

Within this doctoral thesis a new biomechanical support for the ACL reconstruction will be developed. The design solution for the implant will be selected based on computer simulation using the finite element method with 3D models of the knee, created from the reconstruction of the geometry obtained from CT and MRI data. The design solution will also be based on the in vitro experimental testing of a bone-implant set with a displacement measurement using the digital image correlation.

## Preliminary results

From CT and MRI data 3D model of a knee joint was created in the Mimics Materialise software package which is an image processing software for 3D modelling. The finite element method was used for a numerical simulation related to the load causing damage to the ligaments. Numerical simulation was provided using the commercially available finite element program

ABAQUS. The finite element method is a numerical method for solving problems of engineering and mathematical physics based on cutting certain structures into several elements that are parts of that structure and then re-linking these elements in nodes as if the nodes are made of adhesives that hold the two elements together. The result of this process is the set of simultaneous algebraic equations. Numerical simulation is significant for analysis in medicine to understand for what reason something is happening in body under the influence of forces and stresses and is also a basis for experimental testing.

## Discussion

The knowledge and analysis of mechanical and biological properties have important role in better understanding of physical appearance of anterior cruciate ligament and allows better understanding and implementation of the operational process and opens an opportunity for improvement and innovation. Since 3D modelling offers engineers a range of tools that can alter the characteristics of the product to the point where they are satisfied with solutions, followed by prototype or experiment, it can be concluded that such an approach is very educational, as well as desirable in medicine, which further development is associated with further development of technology. Based on previous testing and researches, there is plenty of room for improvement of artificial ACL ligament and replacement of classic surgery with minimally invasive with fast postoperative recovery of a knee. New biomechanical support as a product of this doctoral thesis will not behave destructively to the surrounding tissue and will have good mechanical properties.

## Keywords

Biomechanics, medicine, numerical simulation, support, knee, ACL, stabilization

## Influence Parameters in Computed Tomography Dimensional Measurement

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### Introduction

Period of use of computed tomography (CT) for purposes of dimensional measurements started about 10 years ago and it is still on its beginning. It is a method that has a lot of advantages and can be used for many purposes, e.g. for material inspection, dimensional inspection, in quality control etc. at the same time and with only one scanning of the product. In order to ensure metrological traceability of the method, measurement uncertainty needs to be assessed. Since the CT method has a lot of influencing factors, assessment of measurement uncertainty is a very complicated process. In order to evaluate measurement uncertainty of results according to GUM (Guide to the expression of the uncertainty in measurement), influences of all factors need to be identified and each individual influence on results needs to be specified. Since the CT dimensional measurement is achieved through several stages, influence parameters can be divided according to that criterion into: parameters influencing scanning process, parameters influencing reconstruction process and parameters influencing measurement process. In this research combination of different parameters on measurement results will be investigated and analyzed.

### Methods

Method used for the investigation of the chosen parameters was fractional design of experiment (DOE). The method is used to find cause-and-effect relationships and to manage process inputs in order to optimize the output. In total, observed were seven different input parameters, four of them from first stage of CT dimensional measurement process – CT scanning process – and those were: geometrical magnification, source voltage and current and number of projections; two parameters from reconstruction process: beam hardening filter and data size and one parameter from measurement process:

object determination by choice of threshold value. Observed outputs were dimensional and geometrical characteristics of inspected polymer cylinder.

### Preliminary results

While conducting fractional DOE on measured dimensional and geometrical features of observed object, a correlation between chosen input parameters and output variables was determined. Different combinations of parameters influence results of dimensional and geometrical measurands differently. The parameters that have proved to be significant, both in dimensional and geometrical measurements, are geometrical magnification, threshold value and beam hardening filter.

### Discussion

Determination and mathematical expression of dependencies between selected inputs and measurement results (outputs) was obtained by use of design of experiment. However, because of the lack of metrological traceability, obtained results as well as mathematical models need to be further investigated. The next steps in analysis of input parameters, with aim of more accurate determination of influence parameters, should consider comparison of obtained results with reference measurement values achieved with use of traceable measurement method such as tactile measurement method.

### Keywords

computed tomography, dimensional measurements, influence parameters, design of experiment

## Model of Optimal Maintenance Strategy in Early Stage of Equipment Purchasing Phase

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### Introduction

"Model of Optimal Maintenance Strategy in Early Stage of Equipment Purchasing Phase" is an specific tool which gives possibility to select an optimal equipment supplier during Purchasing phase considering Maintenance strategy for production equipment. Basically, model is based on RCM – Reliability centered maintenance. As support for optimal maintenance strategy development, FMECA – Failure mode, effects and criticality analysis will be used. Model will be able, based on the estimated production losses due to the downtime, to define optimal maintenance strategy in order to minimize total costs. Spare parts optimization will be calculated taking into consideration spare part cost, delivery time and downtime costs. Main idea is to collect, calculate or simulate Maintenance costs for both, Preventive and Corrective maintenance activities and after data pass through it, Model will provide optimal Maintenance strategy for particular equipment. It will be possible to calculate strait influence to the total Production costs. In early stage of purchasing equipment, before choosing a specific supplier, it could be possible to perform a cost-scaling analysis in advance, and determine the supplier whose equipment generates lowest maintenance and consequently lowest production cost.

Usually when developing maintenance strategy, only preventive maintenance activities are taking into consideration and corrective maintenance activities are not. Model will fulfil this gap, it will inspect potential failures, analyse failure consequences due to the costs and connect them to economical part of production – production costs.

Model is based on RCM (Reliability Centred Maintenance). RCM is methodology based on Risk assessment through the application of FMECA (Failure mode, effects and criticality analysis) which is used to analyse potential fail-

ures. Different authors mostly use RCM to develop maintenance strategy during operational phase usually not taking production losses into consideration.

### Methods

An adapted Failure mode, effects and criticality analysis (FMECA) is used to analyse potential failures and downtime costs.

### Preliminary results

By reviewing the literature, it is concluded that is possible to develop model for maintenance strategy in early stage of machine procurement phase executing Failure mode, effects and criticality analysis (FMECA). There is a similar method known as RAM – Reliability, Availability and Maintainability modeling which can be applied during equipment construction phase. When RAM is applied, result is equipment designed to meet high production performances.

### Discussion

Combining of FMECA and economical aspect of failure, by means of consequent downtime costs, will provide useful data. Those data can be optimized in the way to provide model (selection tool) to select the best equipment supplier due to the compliance to the optimal maintenance strategy. "Model of Optimal Maintenance Strategy in Early Stage of Equipment Purchasing Phase" will also take into consideration some aspects of RAM method.

### Acknowledgments

The PhD study and research is financed by Predikta and supported by Belupo.d.o.o.

### Keywords

Maintenance, Maintenance Strategy, Reliability Centered Maintenance (RCM), Failure Mode, Effects and Criticality Analysis" (FMECA)

## Distributed Control of Elastically Interconnected Seesaw-Cart Systems

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### Introduction

Most of the research activities in the field of distributed control have focused on theoretical aspects, and most of the applications are demonstrated by means of simulations due to lack of experimental research platforms suitable for validation of control algorithms and educational purposes. In order to set up a benchmark example, we present a specifically designed network of electro-mechanical systems as a suitable platform for education, testing and verification of real-life implementation of distributed control solutions. Additionally, the synthesis procedure of a set of distributed controllers has been demonstrated.

### Methods

The proposed network consists of physically interconnected seesaw-chart systems. Each subsystem is physically interconnected with its neighbors with elastic link, thereby forming a complex non-linear interconnection of electro-mechanical systems. A structured control oriented model of system's dynamics, which is suitable for distributed control synthesis, is derived by using Euler-Lagrange formalism. Additionally, linear time invariant (LTI) model for relatively small deviations around desired stable equilibrium points is obtained. For the proposed system, we design a set of distributed  $H_\infty$  optimal controllers such that interconnection signals between controller subsystems reflect physical interconnections between seesaws and that the closed-loop is stable while achieving the desired performance.

### Preliminary results

Performance of the distributed controller is compared to a centralized  $H_\infty$  controller which internally stabilizes the system and achieves desired performance of the closed-loop. The response of the closed-loop system with distributed controllers in the presence of external disturbances is simulated and com-

pared with the closed-loop response when centralized controller is used. Similar behavior can be observed in time and frequency responses. As expected, distributed controller achieves somewhat lower performance level, but it is interesting to observe that the difference is relatively low.

### Discussion

Our primary aim has been to present a specifically designed network of electro-mechanical systems as a suitable research and education platform for investigating techniques in distributed control. Results of a case study in distributed control are presented, together with comparison with achievable centralized control behavior.

### Acknowledgments

This work has been supported by Croatian Science Foundation under the project 9354 Control of Spatially Distributed Dynamical Systems.

### Keywords

Distributed control

# Experimental and Theoretical Research of Geothermal Heat Pump

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## Introduction

Ground coupled heat pumps utilize the low enthalpy geothermal energy for the purpose of heating or cooling. Commonly, vertical borehole heat exchangers are coupled to the ground used as a heat source/sink. The proper dimensioning of the system requires knowledge of the thermophysical properties of the ground while both, ground properties and borehole heat exchanger design, affect heat transfer rate and the long-term performance of system. Vertically distributed properties of heterogeneous underground cause varying heat exchange rate along the borehole heat exchanger during system operation. Aim of this research is development of borehole heat exchanger model in stratified ground coupled with the heat pump. Hence, characterization of influence of vertical variability of ground thermal properties on efficiency of geothermal heat pump system and resulting temperature field around borehole is possible.

## Methods

Research includes experimental investigation and simulation of system for analysis of influential parameters. The heat exchanger is coupled to the propane heat pump used for conditioning of the two computer classrooms. Distributed temperature measurements using fiber optic cables placed in borehole heat exchanger are used for obtaining temperature profiles in the ground during system operation. Heat pump system is equipped with temperature, pressure and heat sensors. Also, electric consumption of main components is monitored. Mentioned set up enables calculation of real seasonal performance factor (SPF) and development of the model of heat pump and borehole heat exchanger in stratified underground.

## Preliminary results

Determination of composition and thermal properties of the soil samples is made during drilling procedure. Prior to the thermal re-

sponse test, undisturbed ground temperature profile is measured and geothermal gradient calculated. Distribution of thermal conductivity and borehole resistance is obtained by application of distributed temperature measurements. Temperature profiles during TRT are used for comparison of common methods for averaging the fluid temperature during data processing. Following the initial measurements of the systems, improvement of heat pump cycle have been performed and operating curves of a compressor have been determined. Seasonal efficiency of the heat pump in cooling and heating season have been compared based on first year of system operation.

## Discussion

Vertical variability of ground thermal properties have been investigated in literature in terms of its influence on procedure for determination of effective thermal properties. Based on the results obtained by distributed TRT, modelling of stratified underground is possible. When coupled to the heat pump model, based on the experimental monitoring of the system in use, influence of the vertical variability of ground thermal properties on resulting efficiency of geothermal heat pump system can be observed. Model will be used to analyze effect of different parameters of borehole heat exchanger design and ground properties on the resulting temperature field inside and outside of the borehole, the heat exchanged with the ground and seasonal efficiency of the system.

## Acknowledgments

Research is conducted in the scope of the project "Research and the Promotion of the Use of Shallow Geothermal Potential in Croatia" (Grant no. IPA2007/HR/16IPO/001-040506).

## Keywords

Geothermal heat pump, ground thermal properties, borehole heat exchanger

## Effect of Zinc Oxide Nanoparticles on Structure and Properties of Poly(Vinyl-Alcohol)/Chitosan Blend

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### Introduction

Nanocomposites encompass a large variety of materials made of distinctly dissimilar components and mixed on a nanometer scale. Their properties depend on the properties of their constituents, their morphology and interfacial characteristics. This research focuses on relating structure and mechanical properties of nanocomposites with antimicrobial activity. Organic nanoparticles of chitosan (CS) and inorganic nanoparticles of ZnO, both with cumulative antimicrobial activity are added in a non-toxic poly(vinyl-alcohol) (PVA) matrix. PVA is biocompatible and biodegradable, water-soluble synthetic polymer with good mechanical properties and excellent chemical resistance which is widely used in biomedical field. Chitosan is the second most abundant natural polymer. It is non-toxic, biocompatible and biodegradable natural polymer with antimicrobial activity mostly used as a functional biopolymer in food industry and biomedical applications. Since CS contains hydroxyl and amine groups, it is miscible with flexible PVA due to the formation of hydrogen bonds. CS in the mixture reduces the crystallinity of PVA inducing degradation of mechanical properties. However, the properties of the polymer matrix can be improved by chemical crosslinking with glutaraldehyde (GA) and by adding ZnO nanoparticles. At the interface of polymer blends (PVA/CS) and ZnO it is expected that interphase with reduced molecular mobility will be formed. This will improve the mechanical and barrier properties of the mixture and reduce the negative effect of CS on PVA properties.

### Methods

Polymer solutions with ZnO NPs are casted and then dried in oven in order to prepare flexible films. A solution of low molecular CS in dilute acetic acid is mixed with fully hydrolyzed PVA dissolved in water. The blend is cross-linked

by means of the glutaraldehyde. ZnO NPs are synthesized by precipitation method from zinc sulphate. The molecular dynamics of these one-, two- and three component system and its effect on the mechanical properties are studied by means of dynamic mechanical analysis (DMA).

### Preliminary results

Preliminary results showed that in the  $\tan \delta$  vs temperature graph the a relaxation peak that is attributed to the glass-rubber transition increases both when CS is added to the PVA and when PVA is chemically crosslinked with GA indicating an increase in free volume amount. However, a slight drop and shift to higher temperatures is observed when GA is added into the PVA/CS mixture. CS reduces the crystallinity degree leading to the higher amount of the amorphous phase contributing to a relaxation, but the mobility of the amorphous phase can be restricted with crosslinking.

### Discussion

DMA is an excellent tool for mechanical spectroscopy. From relaxation processes visible in mechanical spectrum, information about structure and mechanical properties depending on temperature can be obtained. It is necessary to perform additional DMA tests, in combination with FTIR spectroscopy, to obtain detailed insight into the nanoparticles influence on the structure and properties of the polymer matrix. An analysis of the barrier properties will also be performed by means of time lag method, in order to show nanoparticles influence on the permeation of small gas molecules through the obtained composite films.

### Keywords

Polymer nanocomposites, ZnO nanoparticles, dynamic mechanical analysis

## Design of Hydrofoils for Small-Scaled Hydrokinetic Turbines Using Genetic Algorithm

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### Introduction

The hydrokinetic turbines represent an emerging technology for the harnessing of a mostly untapped renewable energy contained in river streams, waves and tidal currents. This technology can generate electricity from the flowing water without the use of large dams and reservoirs with a less harmful impact on the environment, which makes it applicable to sites where conventional hydropower technology cannot provide suitable technical, economic and environmentally acceptable solutions. However, the main barrier to their commercialization is relatively low efficiency. The majority of literature focuses on the design improvements of large-scaled hydrokinetic turbines for tidal applications which may be the reason for delayed widespread utilization of kinetic energy contained in rivers and canals.

### Methods

The objective of this study is to provide an efficient approach to the design of small-scaled hydrokinetic turbines with improved hydrodynamic performance by using specially designed hydrofoils. In order to design hydrofoil, characterized by high lift to drag ratio and delayed cavitation inception in the considered operating range of the turbine, the genetic algorithm optimization technique is incorporated in the rotor design procedure. Instead of using multi-objective optimization techniques, that can be quite complex, in this work single objective approximation has been used to meet both criteria by assigning weighting factors. High computational efficiency of the proposed approach is achieved by using B-spline representation of hydrofoil that reduces the number of required control variables in the optimization process, while at the same time keeps wide variety of different hydrofoil shapes that can be obtained.

### Preliminary results

The optimized hydrofoil was compared with other commonly used profiles for hydrokinetic turbines. The new hydrofoil has the highest lift coefficient, as well as low drag coefficient. In addition, minimum coefficient of pressure is high enough which means that cavitation will not occur. Preliminary results, obtained using Blade Element Momentum theory model, show that new hydrofoil can enhance hydraulic efficiency at the rated water speed of 1 m/s.

### Discussion

To validate the results obtained using BEM theory based model, three-dimensional computational fluid dynamics analysis of the turbine will be performed in the future work. The next step will also include an investigation of the impact of enshrouding turbine blades in different shroud geometries. Improved hydraulic efficiency, relative to the efficiency of bare rotor design, is expected as a result of increased flow velocity at the rotor plane.

### Keywords

Genetic algorithm, Design improvements, Hydrokinetic turbines, Hydrofoil optimization, Blade Element Momentum theory

## Preliminary Research on Robust System of Autonomous Agents

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### Introduction

In a variety of applications the presence of humans is to be avoided and their work replaced by the work of robust systems of autonomous agents. Such activities include dangerous, dull and dirty tasks for humans. Examples of the use of autonomous agents are transport of loads and people between multiple locations, non-destructive and irreversible searches of the area, monitoring of natural phenomena, underwater research, traffic control, implementation of communication networks in adverse environments and others. The most commonly used autonomous agents for such tasks are stationary or mobile robots, underwater vehicles, aircraft, agents in a virtual environment, and other types of agents that perform a smaller number of simpler operations, including collecting and processing directly or indirectly measured data on the environment.

During the performance of tasks agents constantly measure their internal and environmental parameters. The capabilities to assess system performance based on the known or estimated agent parameters could enable coordination between the necessary and available use of the autonomous agents system in the early planning stages.

Preliminary research is done on the system of load transport by two rotocopter unmanned aerial vehicles (UAVs) in a static atmosphere. The goal of research is to use a cooperatively flying group of UAVs, each of which is non capable to carry the load solitary.

### Methods

In the first part of the research data was collected on the existing systems of autonomous agents and computed statistical distribution of the parameters. According to the statistical parameters a theoretical framework of model of a system of autonomous agents was developed and analytically solved.

### Preliminary results

The model of a system of unmanned aerial vehicles consists of two rotocoverters transporting load in static atmosphere. Rotocoverters are represented with their generic aerodynamic characteristic. Flight is conducted in atmosphere with constant density and other thermodynamic properties. Configuration of the rotocoverters and the load is fixed during load transport and relative distance between rotocoverters is unique. Load is connected to the rotocoverters with two identical non-extensible ropes and negligible masses, one rope for each rotocopter. All four ends of the ropes are taken to be in the centres of gravities of the corresponding bodies.

The solution of the theoretical model for stationary flights of two rotocoverters carrying one load in a static atmosphere is fully solved. The corresponding power and energy consumption and other characteristics of that form of the rotocoverters was determined, validated and compared with same characteristics of a single rotocopter carrying the same load.

### Discussion

The use of a group of UAVs is better in cases when a loss of one or a several UAVs has non negligible probability, as well as in cases in which the flight path passes through the non characterised or rapidly changing environment, or cases in which the flight path cannot be tracked. This approach, in principle, could utilise simpler, thus cheaper UAVs.

### Keywords

unmanned aerial vehicles, load carrying, measurement, numerical simulations, system of autonomous agents



## **A Model of Innovation Evolution in the Development of Technical Systems**

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### **Introduction**

The development of new technologies is one of the main objectives of today's scientific and industrial development. The companies that are operating in a competitive global environment are trying to improve their development processes, develop new products or to offer new services to the market based on improved or new technologies in order to attain a dominant and advantageous position in the market. Accordingly, current research trends focused on emerging technologies, and their development based on technical inventions, represent an increasingly important part of research and systematic efforts in both academia and the industry. Determining the direction of technology development is an approach used in the industry to support strategic and long-term planning of the development of products, processes and services.

### **Methods**

Data mining is used to extract patent data from online databases. A series of data analysis methods, such as graph theory, statistics, semantic analysis and complex data visualization are employed on the retrieved data set.

### **Preliminary results**

One conference paper has been published while another has been accepted. These papers explored the evolution of an example technology using graph theory, semantic analysis and data visualization as well as other statistical metrics.

### **Discussion**

The purpose of gaining a precise understanding and description of the dynamic relationship between technical invention evolution, their implementation in physical systems and services and market development for such innovation, is to determine (predict) the future direction of technology development. The purpose of this research is to provide insight into the evolution

of technology and attempt to predict its future evolution. Patent analysis is used as the basis of developed models.

### **Acknowledgments**

I would like to thank my parent company CVH d.d. for funding my PhD research as well as my mentor prof. Mario Štorga.

### **Keywords**

innovation management, technology forecasting, patent analysis, data analysis

## Modeling of Product Development Process Using Petri Nets

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### Introduction

New product development process is mostly a geographically dislocated teamwork. In such conditions, coordination and communication between stakeholders become complex problems of primary interest. Even with the support of today's digital systems, one question remains silent: are we sure that the systems for information management are using updated product information in its operation?

### Methods

Several authors argue that PLM systems in the industry do not sufficiently address this question. They do not adequately support communication and exchange of information and knowledge between team members, especially in the case of low granularity of engineering information such as design parameters. The aim of this study is to analyze the possibilities for improvements of design parameter management in teamwork development of complex products. In order to achieve defined objective of this study, a preliminary case study was made. Colored Petri Nets were chosen as a method for process modeling. The question discussed here is about limitations of Petri Nets and how will those limitations affect everyday usage.

### Preliminary results

After the analysis of complex assembly design process, suitability of Coloured Petri nets for modeling dynamics of design parameters was demonstrated. The main focus was on coupled parameters, what means that more than one engineer have an interest in that parameter and engineers have to collaborate and make an agreement about parameter value.

Based on the presented preliminary case study we got the answer to the question. It can be concluded that "classical" (ordinary) Petri nets showed some significant drawbacks in modeling the design parameter dynamics because for any serious industrial application the generated

nets would be too large. Coloured Petri nets, due to their concepts of data, time and hierarchy proved to be a much better method for modeling, simulation and visualization of design parameter dynamics.

### Discussion

The models in Coloured Petri nets are sometimes too abstract and difficult to read and understand. This fact should not be neglected if we want to develop a method and tool which will not burden designers additionally. Based on results of the presented case study we believe that it is worthwhile to continue with the approach where repetitive patterns of communication situations and parts of the design process will be extracted by analyzing information processing and information flows in complex product development environment.

### Keywords

product development, dynamic process, Colored Petri Nets

# Energy Analysis of Heat Exchanger in a Heat Exchanger Network

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## Introduction

For many years now, heat exchanger optimization has been a field of research for a lot of scientists. Aims of optimization are different, having in mind heat exchanger networks with different temperatures of certain streams. In this work mathematical model in dimensionless form has been developed, describing operation of one heat exchanger in a heat exchanger network, with given overall area, based on the maximum heat flow rate criterion. Under the presumption that heat exchanger is part of the heat exchanger network, solution for the given task is resting in a possibility to connect additional fluid stream with certain temperature on a certain point of observed heat exchanger area. The connection point of additional fluid stream determines the exchanging areas of both heat exchangers and it needs to allow the maximum exchanged heat flow rate. In other words, within this mathematical model a criterion for existing of the maximum heat flow rate, as a local extremum, needs to be obtained. This needed heat flow rate amounts higher than heat flow rate acquired by either of streams.

## Methods

This is a theoretical research and the algorithm is given in a dimensionless form. Relevant dimensionless properties of the physical (dimensional) parameters are formed, which appear in a formed algorithm and at the same time represent the parameters describing operating states of the counterflow heat exchanger. Those parameters are: overall disposable heat exchanger area, area of both heat exchangers, their mass flow rates, specific heat capacities of the streams, inlet temperatures as well as overall heat transfer coefficients. Those parameters are used to form the dimensionless model, which is used for analytical obtaining of the local extremum (maximum heat flow rate) existence or non-existence criterion. Thus obtained dimensionless criterion is therefore universal for it covers all of

the operating regimes of such defined counterflow heat exchanger.

## Preliminary results

General criterion is derived, which needs to be fulfilled in order for maximum heat flow rate of the counterflow heat exchanger in a heat exchanger network to be achieved. This criterion is valid for whole interval of ratio of heat capacities. Also, criteria for which maximum heat flow rate will not be achieved are obtained. Results of the research are presented by the adequate diagrams and interpreted, with emphasis on cases which fulfil and those which do not fulfil the given condition for achieving the maximum heat flow rate.

## Discussion

Understanding the needed criterion has a significant importance in design of new heat exchangers as well as in design modifications of existing heat exchangers in actual facilities. It has been shown, when interventions in existing heat exchangers with given overall areas are undertaken, that, to achieve maximum heat flow rate, there is a certain connection point on heat exchanger area for the additional stream. Of course, this concerns design of the new heat exchangers as well.

## Keywords

Heat exchanger network, energy analysis, dimensionless analysis, maximum heat flow rate

## Numerical Simulation of Blood Flow

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### Introduction

Research and development of heart pumps is focused on achieving greater hemocompatibility. Besides stagnation zones and recirculation zones, wall shear stress is parameter that is used to predict pump hemocompatibility i.e., amount of mechanical damage caused by pump on blood cells. Blood is biological non-Newtonian fluid with shear-thinning behavior (viscosity decreases under shear strain) affecting wall shear stress values. In order to calculate wall shear stress and blood flow in heart pump, blood as non-Newtonian fluid has to be numerically modeled.

### Methods

Hemodynamic simulation using OpenFOAM was performed on two-dimensional backward-facing step geometry under laminar incompressible flow conditions. The geometry of two-dimensional backward-facing step is modeled in Salome software package and exported in form of a STL file describing its boundaries (inlet, outlet and wall). After defining computational domain, finite volume mesh of model is created. Idealistic volume flow rate with parabolic velocity profile, based on data presented in Gijssen et al., is defined on inlet boundary. Blood is modeled as incompressible ( $\rho = 1060 \text{ kg/m}^3$ ) non-Newtonian shear-thinning fluid described by Carreau–Yasuda model. Flow downstream of a backward-facing step contains a reattachment point and flow reversal. Hemodynamic simulations are used to obtain velocity, wall shear stress distribution and location of the reattachment point for different volume flow rates on inlet.

### Preliminary results

Numerical and experimental results of wall shear stresses and location of the reattachment point for different volume flow rates are shown. Numerical investigation of the wall shear stress distribution downstream of a backward-facing

step is carried out and compared with experimental results. In general, the non-Newtonian Carreau–Yasuda model provides an accurate prediction of the measured wall shear stress distribution and the location of the reattachment point is predicted accurately for all the flow rates.

### Discussion

The aim of this study was to calculate wall shear stress in a backward-facing step of blood flow and to assess the ability of Carreau–Yasuda model to predict the wall shear stresses. Backward-facing step flow was studied extensively in the past (e.g., Halmos et al., Armaly et al., Pak et al.), enabling detailed validation of the results. The good agreement between experimental and numerical results indicate that the implementation of non-Newtonian shear-thinning Carreau–Yasuda model in OpenFOAM is valid. Research showed that Carreau–Yasuda model in OpenFOAM can be used on steady laminar flow conditions in heart pumps.

### Keywords

Computational fluid dynamics, blood flow, wall shear stress, non-Newtonian fluid, backwards-facing step

# The Developments of the Harmonic Balance Method

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## Introduction

The Harmonic Balance method is a quasi-steady state method developed for simulating non-linear temporally periodic flows. It is based on the assumption that each primitive variable can be accurately represented by a Fourier series in time, using first  $n$  harmonics and the mean value. Such assumption leads to transformation of a single transient equation into a coupled set of steady state equations, each for a different time instant. The benefit of the method, compared to steady state methods, is the ability to capture the transient effects of periodic flows, while providing significant speed-up compared to transient simulation. The Harmonic Balance method will be presented on two turbomachinery test cases and compared to conventional steady-state and transient solvers.

## Methods

The method solves incompressible turbulent periodic flows, while special attention is given to development of turbomachinery applications. It is implemented and tested in foam-extend, a community-driven fork of the open source software OpenFOAM. The Harmonic Balance model is used for accurate and efficient simulation of incompressible turbulent periodic flows, and therefore validated using ERCOFTAC centrifugal pump case and KP505 propeller test case. Results are presented and compared with conventional transient and steady-state simulation. Furthermore, obtained convergence with increase in number of used harmonics is presented.

## Preliminary results

Presenting the two turbomachinery cases, the accuracy and simulation speed-up of the Harmonic Balance method will be demonstrated. A choice on the used number of harmonics  $n$  should be made in order to obtain the optimal accuracy with as few harmonics as possible, therefore keeping the simulation time low. The presented cases were run with up to 7 harmonics, although

the significant level of accuracy was achieved already with 4 harmonics. Geometries used are the well established 2D ERCOFTAC centrifugal pump geometry and a KP505 propeller 3D test case. Steady-state solution with MRF and transient solution will be compared against several Harmonic Balance solutions.

## Discussion

The Harmonic Balance method offers an efficient compromise between accuracy and efficiency as it is capable of capturing transient flow features, while still providing a significant CPU time decrease. Steady state methods lack transient effects, but provide reasonable CPU time savings. On the other hand, transient simulations usually require unacceptably large computational resources in order to achieve periodic steady-state solution, which was demonstrated with the presented test cases.

## Keywords

Harmonic Balance, periodic flow, turbomachinery, CFD, Fourier series

# Primary Energy Return as LCA Based Sustainability Indicator of Waste Management Systems

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## Introduction

Inappropriate waste management and poor resource efficiency are two of the biggest problems which European Union is trying to solve by increasing recycling and reuse and reducing waste disposal. In these circumstances, decision makers need to analyse which of the considered waste management systems leads to higher overall benefits. In this part of research, environmental impact of a waste management system is addressed. The aim of this study was to develop a framework for life cycle energy usage comparison of local waste management systems, which are time dependent, and enable easier decision-making.

## Methods

The framework for life cycle energy usage comparison of local waste management systems is developed by using Cumulative Energy Demand (CED) assessment to display total Primary Energy (PE) consumption for product production, taking into account all relevant front-end processes and provides a useful energy-related screening indicator for Life Cycle Assessment (LCA). Because CED correlates with the majority of environmental impacts assessments it can be used as an indicator for identification of environmentally preferable product and/or system. For this purpose, based on collected empirical data and literature research, estimation inventory data for location-specific conditions have been developed. Starting from the mandatory EU waste management legislation goals this study was performed to analyse and compare different MSW systems, which could be implemented and lead to the fulfilment of EU legislation goals, from the perspective of life cycle energy usage. As the path to legislation compliance is lengthy, this analysis examines time changes in primary energy consumption and return. For easier comparison and decision-making a Primary Energy Return Index is formulated which

is the CED based index calculated by using the LCA-like framework.

## Preliminary results

Results show that time and legislation dependent changes have great influence on decision making related to waste management and interconnected systems. Scenario analysis showed that material recovery scenario saved larger amounts of PE compared to energy recovery scenarios. PERI Index results showed diminishing returns of increasing efficiency of primary waste separation in later years.

## Discussion

Even though material recovery showed better results, by implementation of AD results could be even better. Also, building of WtE incineration based plant made implementation of AD plant in the urban areas easier. Following this, it was concluded that the best results in the field of PE sustainability of WMS could be achieved by combining material and energy recovery of waste.

## Acknowledgments

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## Keywords

Decision-making, municipal solid waste systems, cumulative energy demand, sustainability analysis, energy and material flow tracking,

## Developing an Al-Fly Ash Composite Suitable for Equal Channel Angular Pressing

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### Introduction

Fly ash appears as a side-product of coal combustion in thermal plants. It is a low density material that consists of hollow spherical micro particles, which are basically metal oxides. Previous researches of the composite materials have shown that it's possible to improve the characteristics of aluminium alloys by adding fly ash as reinforcement. Applying Equal Channel Angular Pressing (ECAP) on primarily casted composites, their characteristics are additionally improved. The aim of this research is to develop a casted Al based composite with highest fraction of fly ash, that is suitable for ECAP. Thus achieving: a) resolving the problem of disposal of the fly ash, waste harmful to health and environment, and b) providing a lower price material for the production of light components which are usually made of Al or Al alloys.

### Methods

Composite samples obtained by casting have been cut and subjected to ECAP. This method means that previously prepared material is extruded through an L shaped die. Therefore significant shear forces and reduction of micro grains occur in the material deformation zone, which causes improvement of material characteristics.

Fly ash was sifted and only particles smaller than 45 microns were used. Determination of fly ash components was provided by EDXRF and ICP-OES methods. Samples with 4, 8 and 12 % fraction of fly ash will be extruded four times, with a rotation of 90° in the same direction after each extrusion. Porosity will be inspected on all samples as well as quantitative and qualitative analysis of microstructure by an optical and Scanning Electron Microscope. Micro and macro hardness will be measured by Vickers method. Tribological characteristics of the samples will be determined by solid particles (SiC) erosion.

### Preliminary results

Two different Al alloys were used in this study: A356 and 2024 as metal matrix. During the casting, 4 % of fly ash was added. Casted samples were subjected to ECAP, where problems with the material as well as the tool occurred, caused by severe plastic deformation. The first ECAP die was a multiple part tool. In some of the tests relative movement of certain parts appeared, creating too much clearance and wedging the material between the punch and the die. Hence, a simpler, more durable tool has been made. The A356 alloy, that was primarily intended for casting had shown as a better composite base for ECAP.

A corrosion test has been conducted on the extruded samples, by exposing them to a 3.8 % NaCl solution. Mass variation was measured and the microstructure analyzed. A thicker oxide layer has formed on the samples with fly ash. Deformation had no influence to the process – the results of casted, extruded and pressed samples were similar.

### Discussion

Preliminary results present foundation for further research in purpose of quantification of influence of significant plastic deformation degree at ECAP process and reinforcement fraction to physical, mechanical and tribological characteristics of Al + fly ash composite.

### Acknowledgments

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### Keywords

Fly ash, Equal Channel Angular Pressing, Metal Matrix Composite

