

## **Proceedings of TEAM 2015**

7<sup>th</sup> International Scientific and Expert Conference  
of the International TEAM Society

14–16<sup>th</sup> October 2015, Belgrade, Serbia



# Proceedings of TEAM 2015

7<sup>th</sup> International Scientific and Expert Conference  
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# CONTENT

<b>1. INTEGRITY AND LIFE OF WHEELS REPAIRED BY WELDING</b>	
D. Tanasković, U. Tatić, S. Sedmak, B. Djordjević, J. Lozanović, A. Sedmak .....	1
<b>2. POST HOC ANALYSIS IN BIOMETRICS</b>	
Mario Fröhlich, Tamara Dumančić, Vesna Gantner-Kuterovac and Zoran Škrtić.....	7
<b>3. THE QUALITY OF TABLE EGGS IN RELATION TO THE AGE OF LAYING HENS</b>	
Pavičić Nera, Hell-Kurevija Ana, Fröhlich Mario, Kralik Zlata and Škrtić Zoran.....	11
<b>4. FORMING OF CAR BODY STRUCTURE ELEMENTS BY ELASTIC MEDIUM</b>	
József Danyi, Ferenc Végvári and Gábor Béres.....	16
<b>5. HIGH TEMPERATURE WETTING PHENOMENA BETWEEN MOLTEN BRAZING LIQUIDS AND MULTICOMPONENT (DUAL-PHASE) STRUCTURAL STEELS</b>	
Zoltan Weltsch.....	20
<b>6. ENERGY DEMAND AND SUPPLY IN 21ST CENTURY</b>	
Miroslav Trifunović.....	23
<b>7. THE INFLUENCE OF QUENCHING/COOLING MEDIA ON HARDNESS AND MICROSTRUCTURE OF DUCTILE IRON</b>	
Vladimir Pecić and Štefanija Klarić.....	28
<b>8. MICROSTRUCTURE AND MECHANICAL PROPERTIES INVESTIGATION OF DIFFUSION WELD JOINTS</b>	
J. Urminský, M. Jáňa, M. Marônek.....	32
<b>9. STRUCTURAL TRANSITION IN CULTURAL POLICY: A POST-SOCIALIST PERSPECTIVE</b>	
Tóth, Ákos.....	38
<b>10. MICROSTRUCTURAL EVOLUTION AND MECHANICAL BEHAVIOR OF WC-Co / AISI 1020 STEEL JOINT OBTAINED BY BRAZING AND GTAW PROCESS</b>	
B. Cheniti, D. Miroud and D. Allou.....	45
<b>11. DEVELOPMENT OF ENERGY SUSTAINABLE CONCEPTUAL VARIANT OF THE TECHNICAL SYSTEM KIOSK</b>	
D. Butumović, M. Karakašić, P. Konjatić, Ž. Ivandić and D. Kozak .....	49
<b>12. DESIGN AND EVALUATION OF ROOF STRUCTURES AND FOUNDATION SYSTEMS FOR THE TECHNICAL SYSTEM KIOSK</b>	
T. Morvaj, M. Karakašić, P. Konjatić, Ž. Ivandić and D. Kozak.....	55
<b>13. CONCEPTUAL DESIGN FOR MACHINE TO CUT RAW RUBBER TO RIBBONS</b>	
Z. Štefek, M. Karakašić, Ž. Ivandić and M. Kljajin.....	59
<b>14. ANALYSIS OF DUCTILE IRON METALLOGRAPHIC IMAGES GAINED BY LABORATORY AND ON-SITE METALLOGRAPHY METHODS</b>	
Štefanija Klarić, Zlatko Pavić, Halima Hadžiahmetović.....	64
<b>15. AUTOMATIC EXCHANGE OF GRIPPERS FOR ROBOTIC ARMS IN ASSEMBLY OPERATIONS AS THE BASE FOR FURTHER INDUSTRIAL APPLICATIONS</b>	
Radovan Holubek, Nina Vetríková, Roman Ružarovský, Daynier Rolando Delgado Sobrino and Karol Velišek.....	69
<b>16. THE IMPORTANCE OF SOFT SKILLS IN TECHNICAL EDUCATION</b>	
Danijela Pezer.....	75
<b>17. INFLUENCE OF MINERAL FERTILIZATION ON THE GRAPEVINE YIELD (<i>VITIS VINIFERA</i> L.)</b>	
Mira Sameljak, Teuta Benković-Lačić and Krunoslav Miroslavljević.....	80
<b>18. SIMULATION AND SIMULATION OPTIMIZATION IN THE DESIGN AND ANALYSIS OF THE MATERIAL FLOW AND LAYOUT: THE CASE OF A FLEXIBLE ASSEMBLY CELL</b>	
Daynier Rolando Delgado Sobrino, Radovan Holubek, Karol Velišek, Nina Vetríková, Roman Ružarovský.....	83
<b>19. DETERMINATION OF STRESS THROUGH A STATIC FEM ANALYSIS OF LOCAL RESISTANCE IN THE CENTRAL AREA OF A CHEMICAL TANKER OF 49000 TDW</b>	
Anisoara-Gabriela Cristea, Florentina Palade.....	89

<b>20. THE CHANGES OF THE AUTOMATED ASSEMBLY WORKPLACE WITH THE CAMERA CONTROL SYSTEM</b>	
Nina Vetríková, Radovan Holubek, Roman Ružarovský, Daynier Rolando Delgado Sobrino, Peter Košťál and Karol Velišek .....	95
<b>21. STRESS AND BUCKLING ANALYSIS FOR TOWING HOOK AFT AND TOWING BIT AFT</b>	
F. Palade, A.G. Cristea.....	101
<b>22. METHODOLOGY FOR THE COMPUTATION OF CRITICAL BUCKLING FORCE AT STEEL TUBES WITH FLATTENED ENDS</b>	
S. Kotšmíd, P. Beňo, D. Kozak and G. Królczyk.....	107
<b>23. SOME GENERAL INEQUALITIES FOR CONVEX FUNCTIONS</b>	
Zlatko Pavić, Maja Čuletić Čondrić and Tomislav Aušić.....	110
<b>24. A CRACK APPROACHING AN INTERFACE BETWEEN THE TWO ORTHOTROPIC MATERIALS</b>	
Jelena Djoković, Ružica Nikolić, Aleksandar Sedmak.....	115
<b>25. EXAMINATION OF THE DEVELOPMENT OF PEPPER (<i>CAPSICUM ANNUUM</i> L.) SEEDLING WITH VIRUS VECTOR ON ROCK COTTON MEDIUM IN GLASSHOUSE</b>	
V.J. Vojnich, J. Pető, A. Hüvely.....	120
<b>26. EVALUATION OF WELD JOINTS PRODUCED BY LASER WELDING OF SUPERDUPLEX STAINLESS STEEL SAF 2507</b>	
J. Ertel, J. Bárta, M. Marônek and J. Bílik.....	123
<b>27. PROVING EQUALITIES AND INEQUALITIES BY USING THE INTEGRAL METHOD</b>	
Zlatko Pavić*, Štefanija Klarić, Magdalena Zovko.....	126
<b>29. THE STRUCTURE OF MOTIVATION FOR MECHANICAL ENGINEERING STUDY AT UNIVERSITY OF ZAGREB</b>	
Nikša Dubreta, Damir Miloš.....	131
<b>29. ANALYSIS OF THE PENSION SYSTEM OF CROATIA AND CORRELATION WITH ECONOMIC DEVELOPMENT</b>	
Željko Požega, Marijan Kuprešak and Marko Martinović.....	137
<b>30. QUALITATIVE CHANGES IN HUMAN RESOURCES MANAGEMENT IN SLOVAK ORGANIZATIONS – ARE WE COOPING THE CONTEMPORARY TENDENCIES IN EUROPEAN LABOR MARKET?</b>	
Zuzana Joniaková, Jana Blštáková.....	141
<b>31. APPLICATION OF AHP AND ADDITIVE METHOD IN SUPPLIER SELECTION</b>	
Sara Havrlišan, Katica Šimunović, Tomislav Šarić, Goran Šimunović, Danijela Pezer, Ilija Svalina, Ivan Majdančić.....	149
<b>32. THE ROLE OF PROJECT MANAGEMENT IN THE STRUCTURAL FUNDS OF THE EUROPEAN UNION</b>	
M. Cobović, G. Prebeg and M. Vretenar Cobović.....	154
<b>33. SAFE HANDLING WITH MACHINES FOR PLANT PROTECTION</b>	
Branimir Vujčić, Lejla Safundžić, Siniša Bilić, Jasna Vujčić.....	159
<b>34. PLANT GENETIC RESOURCES AND GENETIC EROSION</b>	
Sonja Marić, Marina Roksandić, Vlado Guberac, Sonja Petrović, Sunčica Guberac, Marija Dundović.....	163
<b>35. SURVEY ON INTRUSION DETECTION SYSTEMS - keynote lecture</b>	
László Göcs <sup>1*</sup> , Zsolt Csaba Johanyák.....	167
<b>36. ANALYSIS OF ACTIVE EMPLOYMENT MEASURES</b>	
Vukajlić, M.....	171
<b>37. INVEX SETS AND PREINVEX FUNCTIONS</b>	
Zlatko Pavić, Vedran Novoselac and Ivan Raguž.....	175
<b>38. ADAPTIVE CENTER WEIGHTED MEDIAN FILTER</b>	
Vedran Novoselac and Zlatko Pavić.....	180
<b>39. OPTICAL MEASUREMENTS OF SURFACE ROUGHNESS CUT WITH WATERJET</b>	
Ivan Nikolić, Miroslav Duspara, Antun Stoić, Ivan Samardžić.....	183



<b>40. DRAWINGLESS MANUFACTURING IMPLEMENTATION</b>	
Peter Košťál, Dávid Tóth, Andrea Mudriková, Marcela Bučányová, D. Delgado Sobrino, Radovan Holubek, Nina Vetríková and Roman Ružarovský.....	189
<b>41. BENCHMARKING AS A STRATEGIC TOOL FOR STRENGTHENING OF THE COMPETITIVENESS</b>	
L. Duspara, S. Knežević, A. Bencun.....	193
<b>42. THE ANALYSIS OF SPORT PRODUCTS IN SLAVONSKI BROD FROM THE STUDENT POPULATION PERSPECTIVE</b>	
H. Sivrić, M. Kušljic and A. Katolik Kovačević.....	197
<b>43. CROSS CULTURAL DIFFERENCES AND THEIR IMPLICATIONS ON CROATIA</b>	
S. Knežević, L. Duspara, D. Miljković.....	202
<b>44. SMARTPHONES POSITIONING ON SAMSUNG EXAMPLE</b>	
A. Katolik Kovačević, V. Vučemilović and M. Aračić.....	206
<b>45. CONFLICT MANAGEMENT IN THE ORGANIZATION AS ONE OF MANAGERIAL SKILLS</b>	
A. Kulaš, R. Ćurak.....	210
<b>46. DISTRIBUTION OF THE ELECTRIC FIELD ACCORDING TO THE EVOLUTION OF THE DISCHARGE IN A SYSTEM POINTED PLANE WITH INSULATING BARRIER</b>	
S. Benharat, S. Bouazabia.....	214
<b>47. NEW METHODS OF MODELLING AND DESIGN OF AUTOMATED ASSEMBLY SYSTEMS BY USING THE SIMULATION TOOL “VIRTUAL COMMISSIONING”</b>	
R. Ružarovský, R. Holubek, D. Delgado Sobrino, N. Vetríková, P. Košťál and K. Velíšek.....	217
<b>48. MONITORING OF WELDING PARAMETERS WITH WELDING MACHINE WELBEE P500L</b>	
Dejan Marić, Miroslav Duspara, Leon Maglić, Antun Stoić, Ivan Samardžić.....	225
<b>49. THE INFLUENCE OF COLD ROLLING ON THE ELECTROCHEMICAL AND MECHANICAL BEHAVIOR OF 316Ti AUSTENITIC STAINLESS STEEL IN ACID SOLUTION H<sub>2</sub>SO<sub>4</sub>.</b>	
Houria Kaddour, Benrabah Imed-Eddine, Taguia Sohaib, Fatah Hellal.....	229
<b>50. QUALITY ASSURANCE AT B&amp;H UNIVERSITIES AND THEIR INTEGRATION IN THE EUROPEAN HIGHER EDUCATION AREA</b>	
H. Bašić, H. Muhić.....	233
<b>51. FRICTION STIR WELDING OF BMG'S: A REVIEW</b>	
Ravi Kumar, Somnath Chattopadhyaya, Aniruddha Ghosh, Ratnesh Kumar and Amit Kumar.....	236
<b>52. MICROSTRUCTURE AND MECHANICAL BEHAVIOR OF TIG BIMETALLIC JOINTS</b>	
M.F. Benlamnour, R. Badji, M. Hadji, A. Boutaghane, N. Bensaid.....	245
<b>53. BUCKLING ANALYSIS OF PERFORATED STRUCTURES MANUFACTURED IN HYBRID COMPOSITE MATERIALS</b>	
L. Belgacem, D. Ouinas.....	249
<b>54. THE RIGIDITY OF THE WALL OF PISTONS IN RELATION TO THE WALL THICKNESS</b>	
Á. Horváth, I. Oldal, G. Kalácska, M. Andó.....	252
<b>55. INFLUENCE OF UV EXPOSURE ON THE MECHANICAL PROPERTIES OF POLYMERIC FILMS USED IN THE CONSTRUCTION OF GREENHOUSES</b>	
Lorand Kun and Alin Constantin Murariu.....	256
<b>56. THE EFFECT OF BORON ON STEELS</b>	
E. Johanyák.....	260
<b>57. FROM BEGINNING TO MODERN ENGINEERING</b>	
Zlatko Pavi, Ivan Raguž .....	266
<b>58. COMPARISON OF MACROECONOMIC INDICATORS OF CROATIA AND IRELAND</b>	
I. Blažević, M. Pelivan and A. Bencun.....	270
<b>59. ENVIRONMENTAL PROTECTION IN INTERMODAL NETWORKS BY MINIMIZING CO<sub>2</sub> EMISSION</b>	
Radoslav Rajkovic, Nenad Zrnic, Đorđe Stakic, Aleksandar Sedmak, Snežana Kirin.....	274
<b>60. ACHIEVING SOCIAL OPTIMUM AND USER EQUILIBRIUM TRAFFIC ASSIGNMENT ON SPECIFIC TEST NETWORK</b>	
Krisztián Medgyes, Rafael Alvarez Gil, Tamás Kovács.....	279
<b>61. THE COMPLEX MEASURING METHOD (CMM) IN EDUCATION</b>	
Iván Devosa, Ágnes Maródi, Tamás Grósz, Zsuzsanna Buzás, János Steklács.....	283
<b>62. SPELT (TRITICUM SPELTA L.) - ENERGY PRODUCTION FROM AGRICULTURAL RESIDUES – keynote lecture</b>	
N. Jovičić, A. Matin, D. Kiš and S. Kalambura.....	287

<b>63. A SIMPLE DIGITAL IMAGING METHOD FOR THE ANALYSIS OF THE COLOR OF FOOD SURFACES</b> Ivana Markovic, Jelena Ilic, Dragan Markovic, Vojislav Simonovic, Sanja Dejanovic, Snezana Golubovic.....	292
<b>64. EVALUATING COMPETITIVE POSITION OF AN AIRLINE COMPANY</b> Bahar Sennaroglu, Egemen Hopali .....	296
<b>65. USING NEURAL NETWORKS TO PREDICT ALUMINIUM OXIDE LAYER THICKNESS</b> P. Michal, A. Vagaská, E. Fečová, M.Gombár, K. Monková, P. Monka.....	299
<b>66. BUSINESS COMMUNICATION COURSE SYLLABI IN UNDERGRADUATE MANAGEMENT AND TECHNICAL EDUCATION IN CROATIA – A COMPARISON - keynote lecture</b> I. Bilić, G. Duplančić Rogošić.....	305
<b>67. DETERMINING THE THEORETICAL FAILURE RATE FUNCTION OF THE THERMAL POWER SYSTEM IN POWER PLANT "NIKOLA TESLA, BLOCK B2"</b> Dragan Kalaba, Milan Đorđević and Snežana Kirin.....	310
<b>68. WEED FLORA OF THE EASTERN LATERAL CHANNEL “JELAS POLJA”</b> R. Benković*, S. Antunović, K. Miroslavljević.....	314
<b>69. MACHINING OF MATERIALS BY ABRASIVE WATER JET TURNING WITH THE PROPOSAL OF ON- LINE MONITORING USING ACOUSTIC EMISSION</b> Ján Cárach, Sergej Hloch .....	317
<b>70. AISI 304 STAINLESS STEEL DISINTEGRATION USING A WATER JET INTENSIFIED BY MECHANICAL VIBRATIONS WITH FREQUENCY OF 20 kHz</b> D. Lehocká, J. Klich, J. Foldyna, S. Hloch, J. Cárach.....	320
<b>71. THE CHALLENGES OF RISK MANAGEMENT OF CRITICAL INFRASTRUCTURE - keynote lecture</b> Kirin S., Keković Z, Kleinheyser B., Brzaković M, Zlatanovic, D.....	324
<b>72. DOES THE AGRICULTURAL PRODUCERS RECOGNIZE THE IMPORTANCE OF BRANDING THE LOCAL PRODUCTS?</b> Dubravka Živoder, Josipa Pavičić*, Petra Tudor.....	328
<b>73. ANIMATION DESIGN IN THE PROCESS OF DEVELOPING A NEW MECHATRONIC PRODUCT</b> T. Pavlic, M. Miletić, B. Hršak, T. Badrov, S. Golubić, T. Vaško, I. Šegrt, R. Jolić, D. Aleksić.....	332
<b>74. THE ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY STUDY OF ULTRAFINE-GRAINED TITANIUM IN ARTIFICIAL SALIVA</b> Dragana Barjaktarević, Ivana Dimić, Ivana Cvijović-Alagić, Jelena Bajat and Marko P. Rakin.....	336
<b>75. CORPORATE SOCIAL RESPONSIBILITY AS A CHALLENGE OF MODERN SOCIETY</b> M. Božić, S. Kirin, S.Borović, S. Lakićević.....	340
<b>76. DYNAMIC BEHAVIOR AND STRESS FIELD OF EXCAVATOR SchRs740 BOOM AS CONSEQUENCE OF TECHNOLOGICAL REQUIREMENT FOR THE INCREASING IN BOOM LENGTH</b> Branko Petrović, Ana Petrović, Dragan Ignjatović and Ines Grozdanović.....	345
<b>77. RELATION RESEARCH OF SITE-SPECIFIC TRITICALE YIELD AND COMBINE SPEED</b> Vojislav Simonovic*, Dragan Markovic, Ivana Markovic, Jovana Šakota Rosić.....	349
<b>78. MAIN ATTRIBUTES OF SME’S INNOVATION ACTIVITY IN SLOVAKIA</b> Ľ. Lesáková1*, P. Laco .....	353
<b>79. INFLUENCE OF FRICTION WELDING PARAMETERS ON HARDNESS, MICROSTRUCTURE AND MECHANICAL PROPERTIES OF THE Al-Cu JOINT</b> Nada Ratković, Dušan Arsić, Vukić Lazić, Ružica Nikolić, Aleksandar Sedmak.....	359
<b>80. STRESS AND DEFORMATION ANALYSIS OF STRUCTURAL MEMBERS OF ONE MULTIPURPOSE KIOSK</b> P. Konjatić, J. Kapetan, M. Karakašić, D. Kozak and Ž. Ivandić.....	364
<b>81. AGING BEHAVIOR AND RESTORATION BY HEAT TREATMENTS OF 2205 DUPLEX STAINLESS STEEL</b> N. Ouali1*, B. Belkessa1 and M. Bouabdallah.....	369
<b>82. SLOVAK AND CZECH FOUNDRIES – BENCHMARKING OF THEIR PROSPECTS IN THE MARKET</b> M. Pokusová, J. Šujanová and E. Hekelová.....	373
<b>83. DUAL TRAINING IN THE LIGHT OF VEHICLE ENGINEERING STUDENT FEEDBACK</b> Erika Török, Zsuzsanna Kovács.....	377
<b>84. RECENT TRENDS IN WHEY UTILIZATION – PRODUCTION OF BIOACTIVE PEPTIDES</b> Tanja Krunić, Slavica Arsić, Maja Bulatović, Maja Vukašinović Sekulić, Marica Rakin.....	382

<b>85. STUDY OF SURFACE MORPHOLOGY OF WATER-JET CUT SURFACE OF FRICTION STIR WELDED JOINT</b>	
Ratnesh Kumar, Dharmendra Kumar Prasad, Shabbir Ali, Sachindra Shankar, Somnath Chattopadhyaya, Ravi Kumar, Sergej Hloch, Michal Zelenak.....	386
<b>86. IMPLEMENTATION OF FIWARE IN INTERNET OF FIELDS</b>	
Nikola Đukić, Branislav Tejić, Srđan Tegeltija, Stevan Stankovski, Dragan Kukolj and Gordana Ostojić.....	391
<b>87. DRILLING OF CFRP-ALUHAB®-CFRP SANDWICH STRUCTURE</b>	
János Liska, Krisztián Kun, Roland Sándor and Norbert Babcsán .....	397
<b>88. ANALYSIS OF THE STRESS FIELD IN A MODEL OF PIPE BRANCHES</b>	
Taško Maneski, Darko Bajić, Nikola Momčilović, Nenad Mitrović, Miloš Milošević, Ana Petrović and Martina Balać.....	402
<b>89. PUBLIC PERCEPTION OF AN URBAN PUBLIC SPACE RECONSTRUCTION</b>	
Tibor Ferenczy.....	406
<b>90. CRITICAL ANALYSIS OF TIG WELDED JOINT OF TITANIUM G-5 ALLOY SHEET</b>	
Deepak Gope, Shubham Yadav, Vipin Kumar, S. Chattopadhyaya, S. Mandal, Sergej Hloch.....	411
<b>91. THE IMPORTANCE OF NUMERICAL ANALYSIS FOR VSR METHOD APPLICATION – CASE STUDIES</b>	
Fuad Hadžikadunić, Nedeljko Vukojević, Safet Isić.....	416
<b>92. ELASTIC-PLASTIC NUMERICAL ANALYSIS OF TENSILE SPECIMENS WITH SURFACE CENTER-CRACKED ASYMMETRIC WELDED X-JOINTS</b>	
E. Doncheva, B. Medjo, G. Adziev, S. Sedmak.....	421
<b>93. MEASURING INTERCULTURALISM USING FUZZY LOGIC</b>	
Janáková Hana.....	426
<b>94. LASER PEENING OF LASER WELDED NICKEL BASED SUPERALLOY SHEETS</b>	
S. Petronic, M. Burzic, D. Milovanovic, K. Colic and S. Perkovic.....	431
<b>95. MECHANICAL BEHAVIOR OF A PIPE SUBJECT TO BUCKLING</b>	
H. Chenine, D. Ouinas and Z. Bennaceur.....	436
<b>96. DEVELOPMENT OF TRAINING PLATFORM FOR POWER PLANT APPLICATION USING VIRTUAL REALITY TOOLS</b>	
R. Beleznaï, G. Dobos, Sz. Szávai and Z. Bézi.....	442
<b>97. NUMERICAL SIMULATION OF DISSIMILAR METAL WELDING - keynote lecture</b>	
Z. Bézi, Sz. Szávai, C. Ohms.....	448
<b>98. MECHANICAL BEHAVIOUR OF PIPES STEEL REINFORCED WITH COMPOSITE MATERIALS AND ON STEEL</b>	
Z. Bennaceur, D. Ouinas and H. Chenine.....	455
<b>99. DEVELOPMENT OF THE SUPPORTING SYSTEM OF AUGMENTED REALITY IN OUTER SPACE FOR THE ENRICHMENT OF TOURIST ATTRACTIONS</b>	
Mihael Kukec, Željko Knok and Nenad Breslauer.....	460
<b>100. DETERMINATION OF IMPACT ENERGY BY DYNAMIC EFFECT OF FORCE ON THE COMPOSITE RUBBER BANDS</b>	
E. Pirić, Z. Burzić, M. Manjgo, F. Islamović, T. Vuherer.....	466
<b>101. WAYS OF RECEIVING INFORMATION IN THE LOCAL ACTION GROUP (LAG) TERRITORY</b>	
I. Mietule, A. Zvaigzne.....	470
<b>102. TEHD CONTACT MODELLING WITH SHELL LIKE LUBRICANT FILM ELEMENT BY FEM</b>	
Sz. Szávai.....	475
<b>103. HEALTH AND KINESIOLOGY ACTIVITY AMONG STUDENTS</b>	
Nevenka Breslauer, Tomislav Hublin and Marija Zegnal Koretić.....	481
<b>104. THERMO-MECHANICAL ANALYSIS OF TANK WAGON FOR TRANSPORTATION OF MOLTEN SULFUR</b>	
Vladimir Milovanović, Nikola Jovanović, Jelena Živković, Aleksandar Dišić, Snežana Vulović and Miroslav Živković.....	485

<b>105. TOPOLOGY OPTIMIZATION USED TO REDUCE WEIGHT OF FOUR-AXLE BOGIE FREIGHT WAGON – keynote lecture</b>	
N. Jovanović, M. Topalović, V. Milovanović, S. Vulović and M. Živković.....	489
<b>106. ROMANIAN EXPERIENCE IN IMPLEMENTING IIW/EFW MANUFACTURER CERTIFICATION SYSTEM</b>	
H. Daşcău.....	493
<b>107. 3D PROFILING OF 12Cr HEAT RESISTANTE STEEL CHARPY V NOCH FRACTURE SURFACES OBTAINED AT DIFFERENT TEMPERATURES</b>	
Gordana Bakic, Milos Djukic, Radivoje Mitrovic, Aleksandar Maslarevic, Zarko Miskovic, Bratislav Rajcic, Vera Sijacki Zeravcic.....	496
<b>108. ANALYTICAL AND NUMERICAL CALCULATION OF THE EQUIVALENT STRESS OF OPEN SECTION THIN-WALLED "U" PROFILE AT CONSTRAINED TORSION</b>	
Đ. Đurđević, N. Anđelić, T. Maneski, V. Milošević-Mitić, M. Milovančević, A. Đurđević.....	502
<b>109. CERTIFICATION AND QUALIFICATION OF NDT PERSONEL, WELDERS AND WELDING INSTRUCTORS IN SERBIA</b>	
Goran Sofronić, Dragana Kuzmanović, Davor Gruber, Vladimir Zorić.....	506
<b>110. USE OF LEARNING OUTCOMES IN ASSESSMENT – NEW PERSPECTIVE BROUGHT BY NATIONAL QUALIFICATIONS FRAMEWORKS IN ENGINEERING HIGHER EDUCATION IN CROATIA – keynote lecture</b>	
M. Balković, D. Kozak and S. Grgić.....	509
<b>111. MANAGING INTELLECTUAL CAPITAL: THE CASE OF MONTENEGRO</b>	
Ana Radunović-Šebek, Djuro Kutlaca.....	514
<b>112. EIGENVALUE AND EIGENVECTOR SENSITIVITY</b>	
Nataša Trišović, Wei Li <sup>2</sup> , Ljubica Milović <sup>3</sup> and Ines Grozdanović.....	519
<b>113. MACROSTRUCTURES, DEFECTS AND MICROHARDNESS OF FRICTION STIR WELDED T JOINTS OF AA 5052-H32 AND AA 5754-H111</b>	
A. Đurđević, A. Sedmak, A. Živković, Đ. Đurđević.....	523
<b>114. INFLUENCE OF INJECTION MOLDING PARAMETERS ON INJECTION MOLDED PART WEIGHT</b>	
Pero Raos, Josip Stojišić.....	528
<b>115. FRICTION STIR WELDING OF T JOINT – NUMERICAL ANALYSIS</b>	
A. Đurđević, S. Tadić, A. Sedmak.....	531
<b>116. BONE CEMENT DEMOLITION BY PULSATING LIQUID JETS - keynote lecture</b>	
Sergej Hloch, Josef Foldyna, Michal Zelenák, Jiří Klich, Pavol Hvizdoš .....	535
<b>117. TWO-SPEED TWO-CARRIER PLANETARY GEAR TRAINS</b>	
Sanjin Troha, Dimitar Karaivanov and EminaDžindo.....	538
<b>118. THE INFLUENCE OF THE SIZE DISTRIBUTION AND PARTICLE PROPERTIES ON THE FILTRATION PERFORMANCES IN TECHNICAL WATER</b>	
Zorana Golubović, Aleksandar Sedmak, Milan Milosavljević.....	543
<b>119. REGULAR ADAPTRONIC PRODUCTS ENHANCED WITH THE FRACTIONAL ORDER CONTROL</b>	
Vasilje Vasić, Mihailo Lazarevic.....	547
<b>120. SUBLIMATION OF VARIOUS MODELS RESULTS OF MULTI-CRITERIA ANALYSIS AS A FUNCTION OF IMPROVEMENT OF ALTERNATIVE RANK RELEVANCE</b>	
Izet Hot, Nazim Manić, Mladen Pantić, Simon Sedmak and Ramo Bakić.....	552
<b>121. SELECTION OF STEELS FOR VITAL STRUCTURES AND TURBINE COMPONENTS OF THE HYDRO POWER PLANT 'DJERDAP 1'</b>	
Miodrag Arsić, Simon Sedmak, Srđan Bošnjak, Mladen Mladenović, Zoran Savić.....	558
<b>122. TECHNO-MANAGERS IN CAPITALISM AND SOCIALISM: COMPARATIVE ANALYSIS OF THE FORD MOTOR COMPANY AND ZAVODI „CRVENA ZASTAVA“</b>	
Milan Stanković, Predrag Markovic.....	565
<b>123. THE ADVANCED MECHATRONIC AGRICULTURE MACHINES - CHALLENGE FOR THE FUTURE -</b>	
J. Melchers, V. Vasić.....	573
<b>124. MOST COMMON PITFALLS WITHIN CREATION OF PROJECT PROPOSALS FOR EU FUNDING</b>	
D. Ninković, I. Svetel, G. D. Grkovic, B. Kleinheyder, E. Engh.....	576

<b>125. DESIGN OF CYLINDRICAL SHELL STEEL STRUCTURES WITH BILLBOARD TOWER AS THE CASE STUDY</b>	
Dorin Radu, Aleksandar Sedmak.....	580
<b>126. MICROMECHANICAL STUDY OF DUCTILE FRACTURE INITIATION AND PROPAGATION ON WELDED TENSILE SPECIMEN WITH A SURFACE PRE-CRACK IN (HAZ)</b>	
Bashir Younise, Aleksandar Sedmak, Marko Rakin and Bojan Medjo.....	585
<b>127. ROLE OF HYDROELECTRIC POWER PLANT IN DEVELOPMENT OF UZICE AND BAJINA BASTA SETTLEMENTS</b>	
Ivana Vučetić, Aleksandra Stupar and Aleksandar Sedmak.....	589
<b>128. REVITALISATION OF ERs 1000 “VEDRICAR” EXCAVATOR DRIVING WHEEL BY WELDING</b>	
Mladen Tošanić, Aleksandar Sedmak, Stefan Tošanić .....	595
<b>129. INFLUENCE OF MACHINING PARAMETERS ON MACHINE TOOL LOADS AT ROTARY ULTRASONIC MACHINING OF SYNTHETIC DIAMOND</b>	
Marcel Kuruc, Jozef Peterka.....	598
<b>130. CERTIFICATION OF PERSONNEL FOR API 510 PRESSURE VESSEL INSPECTOR</b>	
Igor Martić, Galip Buyukyildirim, Tamara Golubović, Ramo Bakic.....	602
<b>131. STRESS INTENSITY FACTOR ANALYSIS FOR A CRACK EMANATING CIRCULAR NOTCH REPAIRED BY COMPOSITE PATCHING</b>	
H.I. Beloufa, D. Ouinas and M. Tarfaoui.....	606
<b>132. MODELLING OF A CRACKED ALUMINIUM PLATE REPAIRED WITH COMPOSITE PATCH IN MODE I AND MIXED MODE</b>	
H.I. Beloufa, D. Ouinas and M. Tarfaoui.....	610
<b>133. DYNAMIC BEHAVIOR OF COMPOSITE PLATES IMPACTED AT LOW VELOCITY</b>	
H. Benyahia, M. Tarfaoui and D. Ouinas.....	614
<b>134. THE IMPACT OF THE CONTACT LOAD RESISTANCE TO ADHESION WEAR OF THERMAL-CHEMICALLY PROCESSED STEEL MnCr</b>	
Ivan Opačak, Dejan Šakić, Vlatko Marušić, Ivan Samardžić.....	617
<b>135. THE INFLUENCE OF PARAMETERS OF THERMOCHEMICAL PROCESSING ON PROPERTIES OF STEEL 20MnCr5</b>	
Ivan Opačak, Luka Marušić, Vlatko Marušić, Dejan Marić.....	622
<b>136. TRANSPARENT BUILDING ELEMENT EFFECTS ON HEAT ENERGY CONSUMPTION</b>	
Arben Ljajić, Ramo Bakic, Nazim Manić and Izet Hot.....	626
<b>137. COMBINED SERBIAN AGRICULTURAL MACHINE FOR TILLAGE FERTILIZATION PREPARATION AND STABILIZATION OF SOIL AND SOWING</b>	
S.Mandić, U. Tatić, B. Đorđević, M. Radojković Tatić.....	629
<b>138. SOME NOTICES ON TRADITIONAL CHALK AND TALK METHOD VS. CONTEMPORARY E-LEARNING</b>	
Dj. Kozić, A. Sedmak.....	632
<b>139 THE PRESMOD LANGUAGE FOR MODELING (2D)</b>	
Željko Popović, Ivan Arandjelović.....	635
<b>140 FATIGUE BEHAVIOUR OF MODELS USING 3D PRINTING TECHNOLOGY</b>	
Jasmina Lozanović Šajić.....	638
<b>141 WELD REPAIR OF A P91 STEAM PIPE WITH OVER 100.000 OPERATING HOURS EXHAUSTED LIFE</b>	
C. Delamarian.....	642
<b>142 GEOMETRIC PROGRAMMING FOR OPTIMAL DESIGN OF A WELDED ASSEMBLY: AN ILLUSTRATIVE EXAMPLE</b>	
B. Pejović <sup>1</sup> , D. Stević <sup>1</sup> , I. Hut <sup>2</sup> , V. Mičić <sup>3</sup> , A. Sedmak.....	646

# TOPOLOGY OPTIMIZATION USED TO REDUCE WEIGHT OF FOUR-AXLE BOGIE FREIGHT WAGON

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## Abstract

*The goal of this paper is to show the application of topology optimization for reducing the weight of different types of construction, especially freight wagons. In the first part of this paper a short introduction on optimization techniques is given and characteristics of analyzed model are discussed. In the second section process and results of topology optimization applied on freight, four-axle bogie wagon are given. Final part of the paper includes discussion about achieved results and comments about usefulness of topology optimization.*

**Keywords:** Optimization, topology, wagon

## 1. Introduction

Maximum speed of freight wagons is limited by the weight of wagons and cargo and their high center of gravity, because the centrifugal forces could cause derailling in short radius curves [1]. In order to have a competitive product in an ever demanding market, engineers must pay attention to weight reduction during design process, which lowers wagon center of gravity, material used, and unit production price [2]. Before exploitation starts, wagons must satisfy rigorous safety standards [3]-[6]. Numerical methods such as the Finite Element Method (FEM) are used to test various shape configurations, and wagon response to different loading condition without need to create prototype which reduces design time and improves overall wagon characteristics [7]. Designers must verify every change they make with a series FEM analysis to check if the new design satisfies all loading conditions prescribed in the standards [3]-[6]. This process can be very tedious, but it can be automated using optimization [8]. Optimization is the process of design improvements by finding best results under given conditions.

In railway industry optimization is not implemented enough, but in recent years, several examples of optimization implementation are published, such as management of freight wagon distribution [9], material selection [10], or composite material design [11]. These examples do not refer to changes of wagon structure, but to the other aspects of wagon design and implementation.

Optimization of wagon structure is given in [12], where parametric optimization is used to reduce freight wagon mass. There are three kinds of structural optimization: parametric (size) optimization (which is presented in [12]), shape optimization and topology optimization which is presented in this paper (Fig. 1)

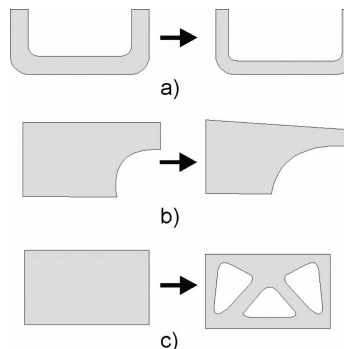


Figure 1. Structural optimization: a) parametric optimization; b) shape optimization; c) topology optimization

Parametric optimization changes only properties of the structures while geometry remains the same [13]. Shape optimization changes dimensions and shape of existing features, and topology optimization implies creation of new features, mostly free shape openings for even stress distribution. Shape and topology optimization are much more complicated and more difficult to implement because it performs changes to object geometry which requires changes in FEM mesh [14] or creating new design analysis model according to which topology optimization is done. Changes of geometry during topology optimization results in new FEM mesh at the end of the optimization process [15]. In this paper results of topology optimization of freight wagon are presented. Reduction of mass is achieved by creating and changing geometry of holes that are cut out of the heavy supporting structure where internal stresses are significantly lower than maximum allowed stress defined by mentioned standards.

## 2. Description of the used model

Wagon analyzed in this paper is freight, four-axle bogie wagon, and it is designed to transport gravel and iron ore. To satisfy condition defined by standards total of 18 analysis using FEM Method are done to confirm static and fatigue strength.

The wagon is modeled using the Femap software with NX Nastran solver, which operates based on the finite element method. According to the construction type, shell elements of the appropriate thickness and 3D elements (for modeling of the support plate, compensating ring, traction stop) were used for creating the finite element mesh. The structure is modeled in details with 236658 elements and 234700 nodes. General element side length is about 35 mm. Figure 2. shows the 3D model of the whole wagon without bogies.



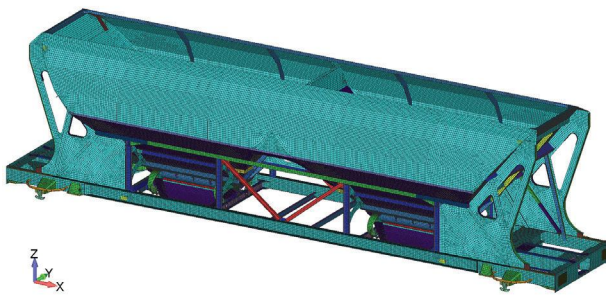


Figure 2. 3D Vehicle model

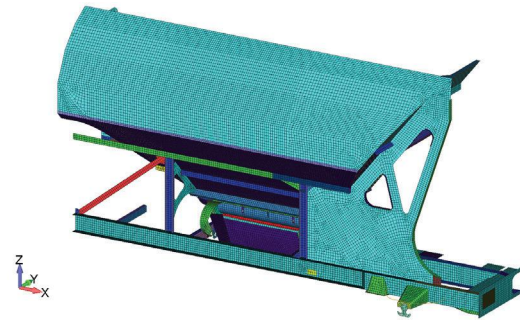


Figure 3. 3D Vehicle model – one quarter

Colours in Figure 2. match the various thicknesses of shell elements. Figure 3 shows a quarter of the model, which will be used, taking in consideration correspondent symmetry of the load cases.

Full model was used for unsymmetrical load cases and a half model for analysis of wagon lifting.

The Models shown on Figure 2. and Figure 3. are final experientially optimized models used for final analysis and correspond to the real construction. However, the goal of this paper is to show advantages in using advanced software as a tool in engineering practice during problem solving and optimizing the design of products.

### 3. Topology optimization and its results

Topology optimization is a process of searching for the optimal solution of problem which has one or more constraints involved. Traditional approach to optimization implies a method of trial and error, where engineer relies on his own knowledge and experience. With the application of topology optimization process on optimizing construction of wagons, process itself can be accelerated and more efficient, saving time and reducing the cost of final product. Algorithm of the traditional approach of optimization and software aided approach are shown in Fig. 4.

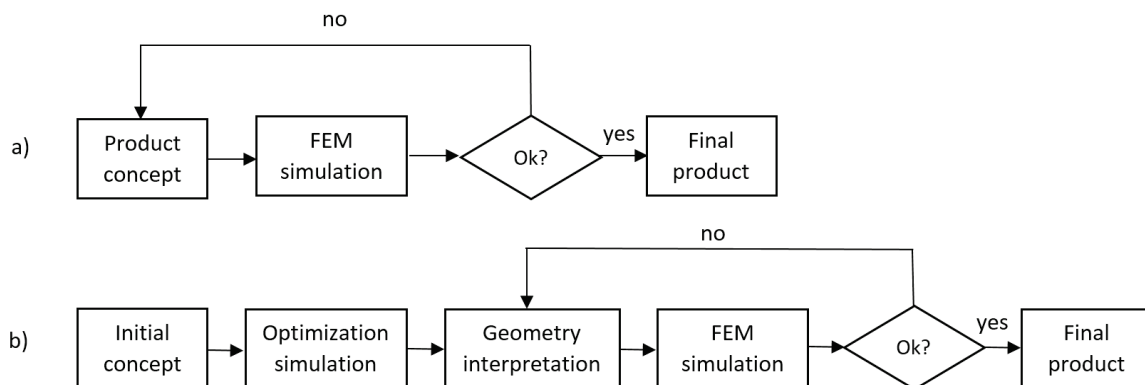


Figure 4. Types of approaches to optimization: a) Traditional approach; b) Software aided approach

Results and principle of study will be shown on one quarter of the wagon due the better visualization and the existence of symmetry. The goal of optimization is the mass reduction because the construction before the optimization exceeded the maximum allowed mass. Initial mesh used for representation of corresponding geometry is shown in Fig. 5.

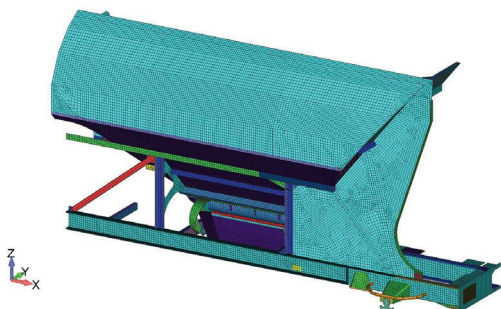


Figure 5. 3D Vehicle model – Initial configuration

The surface shown on figure 6 is chosen as a surface suitable for topology optimization, because it can be seen experientially that there is a large unused area on which, except in some regions, there is no high values of equivalent stress field.

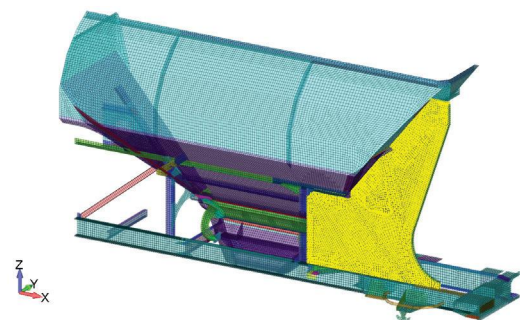


Figure 6. Surface chosen for optimization

When defining the topology optimization parameters, multi set option is used which takes into account existence of all types of loading and all types of constraints.

Volume reduction up to 50% is set as a goal function, while keeping the same stiffness of construction is a constraint. After setting all the parameters, the following results were obtained.

Modified shape of optimized surface in comparison to the initial configuration is shown on Fig. 7.

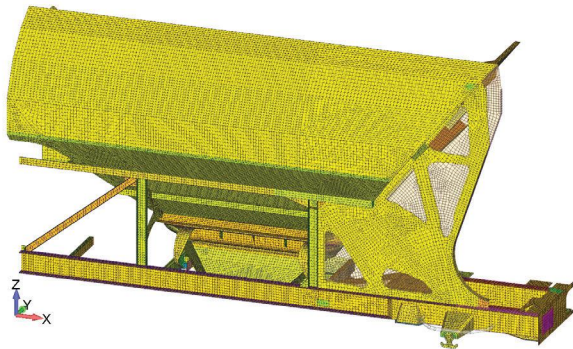


Figure 7. Optimized shape of the chosen surface

Process of topology optimization in NX Nastran is iterative and uses a gradient based algorithm. Function that shows decrease of volume per iteration is shown in Fig. 8.

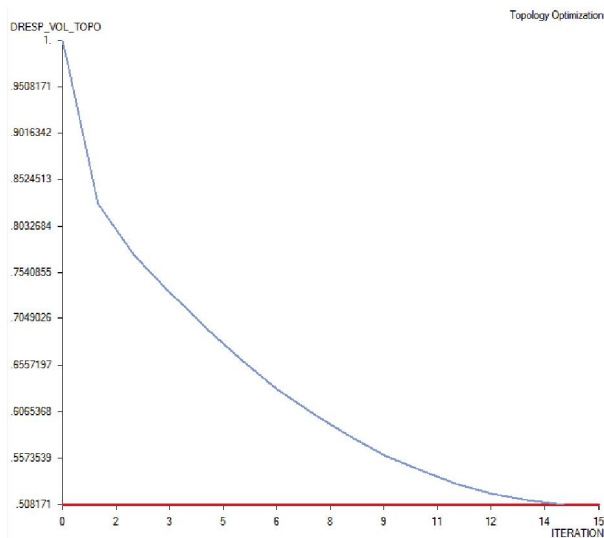


Figure 8. Volume decrease per iteration

From Figure 8. it can be seen that optimizer managed to find optimum of it's goal function and reduce volume to 50%.

Besides the volume reduction, optimizer had to keep stiffness at the same level or to increase it if possible. The value of stiffness during the iterative procedure of decreasing the volume is shown on Fig. 9. From this figure it can be seen that there were no stiffness reduction, but on the contrary the value of stiffness has increased by 14%. Final optimizer suggested model is shown on Fig. 10.

From Figure 10. it can be seen that the suggested optimized shape of surface is not ideally technological and for final construction geometry of new openings must be represented on some more suitable way.

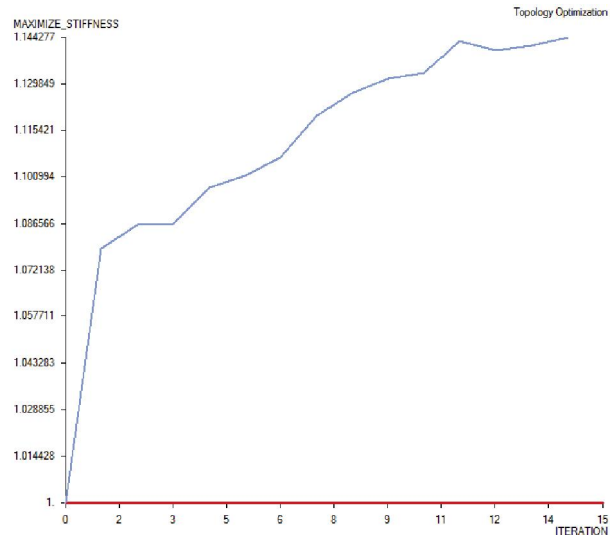


Figure 9. Value of stiffness per iteration

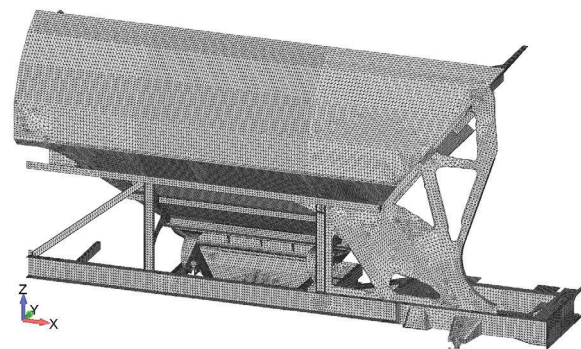


Figure 10. Optimized shape suggested by optimizer

#### 4. Difference between topology optimized and experiential model

Parallel display of the experientially and topology optimized shape is shown of figure 11.

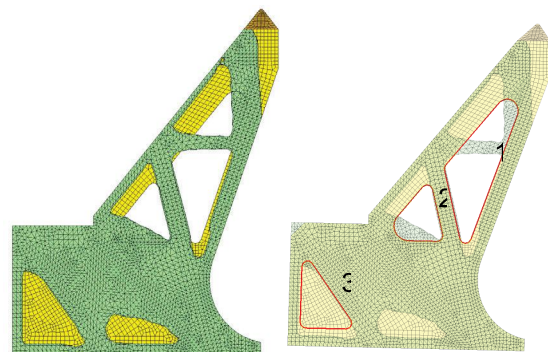


Figure 11. Experientially and topology optimized shape of surface



In Fig. 11 experientially created openings are shown with the red line for better visualization. Opening, labeled with the number 3, is later removed due the customer request, because they planed to put there a panel with description of wagon.

According to the obtained results, it can be seen the big similarity between the experientially and topology optimized shape. Positions and size of openings in both cases are approximately the same. The biggest difference is in time spent on getting the satisfactory results. Time used for topology optimization is much less than time spent for trial and error method. Savings in the mass are given in Tab. 1.

Table 1. Mass of the optimized surface

Initial configuration [kg]	Topology optimized [kg]	Experientially Optimized, [kg]
122.21	69.08	89.6

It can be seen from Table 1 that saving of 26.68% is achieved in the final configuration. The difference in mass on one quarter is 32.61kg and multiplied by 4 is 130.44kg for entire wagon.

## 5. Conclusion

Reviewing the savings in the mass it can be seen that the total weight of wagon is not significantly reduced by this optimization, nevertheless it should be remembered that this is just one surface optimized with possibility of optimizing much more. In that way of thinking it can be seen that the accumulation of this kind of savings brings to much more weight reduction.

Although once started optimization runs independently from the engineer, validity of results completely depends on the engineer. This is because the parameters of the optimization: goal function, constraints, types of loads, etc. are something that engineer chooses based on his knowledge. The optimizer can not change input parameters or to examine if they are properly chosen by the engineer. Thus, it can be concluded that optimization is useful tool in the process of product design.

## 6. Acknowledgement

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