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# Proceedings of the 16th International Symposium on OPERATIONAL RESEARCH in Slovenia

# SOR '21

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Edited by:

S. Drobne • L. Zadnik Stirn • M. Kljajić Borštnar • J. Povh • J. Žerovnik

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# *Preface*

*This volume, Proceedings of the 16th International Symposium on Operational Research, called SOR'21, contains papers presented at SOR'21 (https://sor.fov.um.si/), organised by Slovenian Society INFORMATIKA (SDI), Section for Operational Research (SOR), University of Maribor, Faculty of Organisational Sciences, Kranj, Slovenia (FOV), and University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia (UL FS). The SOR'21 symposium, held 22-24 September 2021, was originally planned to take place in Bled, Slovenia, but was moved online due to the situation of COVID-19 in Slovenia and beyond. The volume contains blind peer-reviewed papers or abstracts of papers presented at the symposium.*

*The opening address at SOR'21 was given by Prof. Dr. Lidija Zadnik Stirn, President of SOR, Mr. Niko Schlamberger, President of SDI, representatives of FOV and UL FS, Prof. Dr. Mario Jadrić, President of Croatian Operational Research Society (CRORS), Dr Sarah Fores, manager of The Association of European Operational Research Societies (EURO), and presidents/representatives of some others Operational Research Societies from abroad.*

*SOR'21 is the scientific event in the field of Operational Research, another in the traditional series of biennial international OR conferences organised in Slovenia by SDI-SOR. It is the continuation of fifteen previous symposia. The main objective of SOR'21 is to promote knowledge, interest and education in the field of OR in Slovenia, Europe and worldwide in order to build the intellectual and social capital essential for maintaining the identity of OR, especially at a time when interdisciplinary cooperation is proclaimed as particularly important for solving problems in today's challenging times. By joining IFORS and EURO, the SDI-SOR has also agreed to collaborate with different disciplines, i.e., to balance the depth of theoretical knowledge in OR and the understanding of theory, methods, and problems in other fields within and outside OR. We believe that SOR'21 creates the advantage of these goals, contributes to the quality and reputation of OR by presenting and sharing new developments, opinions and experiences in the theory and practise of OR.*

*SOR'21 was highlighted by five distinguished keynote speakers. The first part of Proceedings SOR'21 contains invited abstracts, presented by five outstanding scientists: Assist. Prof. Nikolina Ban, University of Innsbruck (UIBK), Department of Atmospheric and Cryospheric Sciences, Innsbruck, Austria, Assist. Prof. Vedran Kojić, University of Zagreb, Faculty of Economics & Business, Zagreb, Croatia, Prof. Panos Patrinos, KU Leuven, Department of Electrical Engineering (ESAT), STADIUS Center for Dynamical Systems, Signal Processing and Data Analytics, Leuven, Belgium, Prof. Suresh P. Sethi, Eugene McDermott Chair Professor of Operations Management, Director, Center of Intelligent Supply Networks, Naveen Jindal School of Management, The University of Texas at Dallas, Dallas, USA, and Prof. Jerneja Žganec Gros, Alpineon Ltd, Ljubljana, Slovenia.*

*The Proceedings includes 118 papers or abstracts by 240 authors. Most of the authors of the contributed papers came from Slovenia (82), then Croatia (52), Hungary (23), Portugal (23), Serbia (17), Poland (9), Czech Republic (8), Slovak Republic (7), Spain (6), Netherlands (4), Bosnia and Herzegovina (2), Austria (1), Belgium (1), France (1), Germany (1), Romania (1), Ukraine (1), United Kingdom (1), and United States of Amerika (1). The papers published in the Proceedings are divided into Plenary Lectures (5 abstracts), eleven special sessions: Application of Operational Research in Smart Cities (6 papers), Computational Mathematical Optimization (7 papers and 6 abstracts), Data Science – Methodologies and Case Studies (10 papers), Graph Theory and Algorithms (2 papers),*

*High-Performance Computing and Big Data (3 papers), Industry & Society 5.0: Optimization in Industrial and Human Environments (6 papers), International Projects in Operations Research (2 papers), Lessons Learned from the COVID-19 Pandemic: Applications of Statistical and OR Methods (8 papers), Logistics and Sustainability (9 papers), Operational Research in Ageing Studies and Social Innovations (5 papers), Operations Research in Agricultural Economics and Farm Management (5 papers), and eight sessions: Econometric Models and Statistics (6 papers), Environment and Social Issues (5 papers), Finance and Investments (6 papers), Location and Transport, Graphs and their Applications (5 papers), Mathematical Programming and Optimization (5 papers and 1 abstract), Multi-Criteria Decision-Making (10 papers), Theory of Games (3 papers), and Problems Approaching OR (3 papers).*

*Proceedings of the previous fifteen International Symposia on Operational Research organised by the Slovenian Section on Operational Research, listed at https://www.drustvo-informatika.si/sekcije/sor/sor-publikacijepublications/, are indexed in the following secondary and tertiary publications: Current Mathematical Publications, Mathematical Review, Zentralblatt fuer Mathematik/ Mathematics Abstracts, MATH on STN International and CompactMath, INSPEC. It is expected that Proceedings SOR'21 will be covered by the same bibliographic databases.*

*The success of the scientific events at SOR'21 and of the present conference proceedings should be seen because of joint efforts. On behalf of the organisers, we would like to express our sincere gratitude to all those who assisted us in the preparation of the event. Without the dedicated and advice of the active members of the Slovenian Operations Research Section, we would not have been able to attract so many top-class speakers from all over the world. Many thanks to them. In addition, we would like to express our deepest gratitude to the prominent keynote speakers, the members of the Programme and Organising Committees, the reviewers who improved the quality of SOR'21 with their useful suggestions, the section chairs and all the numerous people - far too many to list individually here - who helped in organizing of the 16th International Symposium on Operational Research SOR'21 and compiling this proceedings. Finally, we thank the authors for their efforts in preparing and presenting the papers that made the 16th Symposium on Operational Research SOR'21 a success.*

*We would like to give special thanks to the Partnership for Advanced Computing in Europe (PRACE) for their financial support.*

*Ljubljana and Kranj, September 22, 2021*

*Samo Drobne*
*Lidija Zadnik Stirn*
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# *Contents*

# THE ROLE OF INTERMODAL TRANSPORTATION ON REDUCING $CO_2$ EMISSIONS

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**Abstract** Intermodal transport is a driver for reducing $CO_2$ emissions and offers solutions with low $CO_2$ content and low costs. The objective of this article is to identify the combination of intermodal transport that emits the lowest $CO_2$ content into the atmosphere through the design and analysis of several possible scenarios, using a $CO_2$ calculator available online (DHL Carbon Calculator). Different scenarios of intermodality were created and the results were analysed in relation to the indicators of $CO_2$ reduction, cost and time of transport and distance.

**Keywords:** Sustainability, Intermodal Transport, $CO_2$ Emissions.

## 1 INTRODUCTION

Over the last years the possibility of industries operate in a global market, has been contributing to increase the transportation of goods by highways. The transportation is considered a key sector for several countries but is also considered as one of the main sources of $CO_2$ emission [1].

The increase of freight transport in the global market has increased concerns regarding the negative impacts on air quality and climate change. Since transport is mainly driven by the combustion of fossil fuels, which results in the emission of various greenhouse gases such as carbon dioxide ($CO_2$), nitrogen (NOx) and Sulfur oxide (SOx) [2].

According to data estimated by International Energy Agency [3], $CO_2$ emission in the transport sector represented about 24% in 2020, and it expects to continue growing in the coming years. The transport sector is constantly changing due to technological advances, it has been contributing to find solutions for freight transport more efficient in terms of time and costs. In doing so, the intermodality in transportation has gaining ground as a system for transporting goods over long distances, resorting different types of transport, such as, ports and includes coastal routes, waterways, railways, roads, and airways [4].

Traditional models of logistics management are concerned with minimizing transport costs, but due to the increase number of $CO_2$ emissions in the last decades, it is imperative the development of new models and technologies to support companies in minimizing and controlling it [5]. Considering the importance of intermodality in transports as a strategy to minimize $CO_2$ emissions, this research aims to analyse the contribution application of intermodality to reduce the emission generated by a furniture company, namely the IKEA company. Then, identify the combination of intermodal transport that produces the lowest $CO_2$

content into the atmosphere through the design and analysis of several possible scenarios, using a $CO_2$ calculator available online, at a commercial company.

## 2 METHODOLOGY

This research focuses two main sources of data, namely the DHL Carbon Calculation, which is a platform widely used by companies and researchers to quantity $CO_2$ emissions in the transportation, considering different scenarios and transport modal and data from IKEA company public reports.

The calculation of $CO_2$ emissions used in DHL's Carbon Calculater can be found online and free of charge on the DHL platform [6]. The methodology used in the platform is in line with the reports published by IPCC (See [7]), which focusing on the role of transportations on mitigating climate change. This works was also inspired in the work developed by Lagoudis and Shakri [8], in this research a framework to measure carbon emissions for inbound transportation was developed, taking into consideration cargo distribution between air and sea as variables. For the creation of the scenarios some aspects were considered, namely the cost of transport and the time required for transport, and then these values were used to estimate calculated using data provided by a forwarding company.

In this research, the $CO_2$ values on the "SCENARIOS" represent the $CO_2$ emission from the combustion of fossil fuels used to transport the configured shipment scenario. The emission calculations are based on the guidelines outlined in the Greenhouse Gas Protocol, the Corporate Accounting and Reporting Standard and the Corporate Value Chain Accounting and Reporting Standard.

The data were also prepared in accordance with the requirements of the European Emissions Trading System and the standards EN 16258 [9] and ISO 14064 [10]. For the creation of the scenarios, The Carbon Calculator was used considering the waypoints between a pair of origin and destination location, based on a network data set specific to the mode of transport, and links the waypoints to build a route. The sum of all connected waypoints shows the shortest distance travelled on that route. If a location is inserted that is not part of the mode-specific network data set, using a built-in algorithm, the Carbon Calculator adds a connection from that location to the nearest location that is part of the mode-specific network data of joint transport.

In order to get a picture of $CO_2$ emission generated by transports of products by IKEA company a set of scenarios was created. In doing so, this research has considered three routes Matosinhos (PT) - Valls (ES); Penamaior (PT) - Erfurt (DE); Tábua (PT) - Piacenza (IT). Through the help of DHL Carbon Calculater, we were able to determine the ideal scenario for each route.

## 3 IKEA CASE STUDY

The environment can affects the business of organizations in several ways, including the scarcity of resources, the socio-demographic context, and the presence of competitors. As a consequence, over the last decades companies have been pushed to develop projects in the planning and construction of strategies to minimize the cost of its impacts on the environment, the transport has been seen as longwinded part of these strategies, especially when defining routes to transport companies goods [11].

In this research the IKEA company was used a case study to illustrate the impact of transportation on climate footprint. Since intermodality in transports, can be considered as a driver towards reducing $CO_2$ emissions, and offering solutions that produces a low $CO_2$ content and low costs, we focused on suggesting a set of alternatives for transportation of the company's products in more sustainable way.

In the last report published by IKEA in 2020 for the previous year, the company points out that its biggest long-term goal is to reduce its climate footprint by the year 2030 compared to 2017, in which the footprint value was 1.2 million tons of $CO_2$. IKEA is a company with great concern regarding sustainability and environment impacts. For this research, the combination of different modal transport was considered aiming to propose the lowest $CO_2$ content emitted. As presented in Table 1, for the calculation of $CO_2$ emissions, three routes were identified from where transport will be dispatched to the destination:

*Table 1: Proposed scenarios for the case study.*

| Scenarios | ***Route*** | |
|---|---|---|
| | Origin | Destination |
| S1 | Matosinhos, PT | Valls, ES |
| S2 | Penamaior, PT | Erfurt, DE |
| S3 | Tábua, PT | Piacenza, IT |

The locations for the departure of goods transport and reception, were chosen since, in these cities, IKEA has stores and distribution centres. For the development and calculation of scenarios, it is necessary to consider some assumptions directly related to the adopted cost values, and these values were identified by a freight forwarder with extensive experience in the market:
(1) Regarding road transport, the cost of traveling will be calculated according to the number of kilometers travelled. (2) Routes with less than or with 100Km were estimated by a cost of 100 €. In these cases, it was not possible to count the cost of traveling the route as it is not compensatory for freight forwarders, since there are fuel costs, maintenance costs, delays in loading and unloading which can lead to the fact that they are no longer able to do the next service. Thus, it is necessary to estimate a value that can cover all possible costs. For journeys over 100 km, the estimated cost will be 1 euro per kilometer. (3) For the sea mode, the values were estimated according to the destination. Therefore, the cost of sea freight to Spain will cost 950 €. For Germany, Sea freight cost 1250 € and finally, for Italy the cost 1150 €. It always adds to the value of the Sea freight, whatever the destination, the value of the tax-rate that is the rate that is always charged due to the pollution that is emitted by maritime transport. In this case the value used as an estimate was 25 € but this value is updated every month. (4) For the railway mode, it is necessary to consider the cost of rail freight, which also varies according to the destination and the handling cost, which is the cost that the terminal has in handling the loads, and a fixed value of 20 € per movement is estimated. The cost of rail freight to Spain is approximately 400 €, to Italy 500 € and to Germany 600 €.

Table 2 details the configuration for each combined scenario, considering the Starting point to destination point.

*Table 2: Details of chosen routes.*

| ***Route*** | ***Matosinhos (PT) – Valls (ES)*** | ***Penamaior (PT) – Erfurt (DE)*** | ***Tábua (PT) – Piacenza (IT)*** |
|---|---|---|---|
| ***S1*** | *Road* | *Road* | *Road* |
| ***S2*** | *Road – Rail- Road* | *Road – Sea - Road* | *Road – Sea - Road* |
| ***S3*** | *Road – Sea - Road* | *Road – Rail- Road* | *Road – Rail- Road* |
| ***S4*** | *Road – Sea –Rail- Road* | *Road – Sea –Rail- Road* | *Road – Sea –Rail- Road* |

For each route aiming to understand the difference between transport mode, a set of scenarios was suggested, as summarized in the Table 2, three cities in Portugal were taken as sample, and then three different countries were chosen, namely Germany, Spain, and Italy. These countries were chosen because IKEA has large distribution centres in these countries.

## 4 RESULTS AND DISCUSSION

The results presented in this section summarizes the novelty of this research, which lies in two main aspects, namely, to bring to the light the need for further discussion by companies on understanding their environmental impact of transportation and, the contributing of intermodality as a logistics strategy to reduce $CO_2$ emission. After defining the configuration of each route selected, the first analysis was carried out. Here is important to highlight that for all scenarios a total of 20 tons of products was considered in each route transportation. Since this research focused on quantifying emissions for different routes, the next sections will be discussed detailing the results achieved for each one of them.

### 4.1 Matosinhos (PT) - Valls (S)

For the case of Matosinhos (Portugal - PT) - Valls (Spain - S) route, the results from Table 3 shows that scenario 1 was considered as the one most effective in terms of the number of kilometers and in terms of transport time, on the other hand, scenario 2 is the most effective at level of costs and number of $CO_2$ emissions.

*Table 3: Results for Scenario Matosinhos (PT) - Valls (S)- PT-S_S1 -S4*

| | ***Distance (Km)*** | ***Cost (€)*** | ***Time (hour)*** | ***$CO_2$ Emission (KgCO2)*** |
|---|---|---|---|---|
| ***PT-S_S1*** | 1063 | 1063 | 13 | 944,05 |
| ***PT-S_S2*** | 1247,44 | 659,16 | 20 | **502,23** |
| ***PT-S_S3*** | 2434,52 | 1163,19 | 50 | 647,19 |
| ***PT-S_S4*** | 2549,33 | 1849,47 | 72 | 1408,13 |

For scenarios 3 and 4, the results showed that they were considered as not successful on the variables chosen for study because the distance, costs and emissions has a higher value. Scenario 3 combines the road and sea mode; this modality contributes the value of each variable to increase significantly. This increase is due to the fact that we use the sea mode and the location of the destination. The freight from Leixões Port – Portugal to Barcelona, has a cost of almost 1000€, and it takes about 48 hours, with a distance travel of approximately 2325.84Km. In terms of $CO_2$ emission, the results showed that the route emits about 550.69Kg$CO_2$. When compared to scenario 1, PT-S_S3 would be more effective in terms of costs and $CO_2$ emissions, but in terms of time and kilometers it would no longer be, as it takes more time and travels more kilometers. Thus, PT-S_S2 was considered as the most effective intermodality proposal for the Matosinhos (PT) - Valls (ES) route, since the one that contains lower costs and a low $CO_2$ emission level.

### 4.2 Penamaior (PT) – Erfurt (DE)

Regarding the Penamaior (PT) - Erfurt (DE) 4 scenarios were also considered, for this case, the results showed that route PT-DE_S1 was considered as the most effective in terms of the number of kilometres and time. PT-DE_S1 was pointed out as positive in terms cost-effective. Finally, for the case of PT-DE_S4 the results put in evidence the effectiveness of the scenario in terms of $CO_2$ emissions. Despite not being effective in any of the variables, PT-DE_S4, presents a very attractive number of $CO_2$ emissions compared to scenario 3 and scenario 1. In this scenario, 3 modes of transport were considered, namely road, sea, and rail.

*Table 4: Results for Scenario Penamaior (PT) - Erfurt (DE) Results*

| | ***Distance (Km)*** | ***Cost (€)*** | ***Time (hour)*** | ***$CO_2$ Emission (KgCO2)*** |
|---|---|---|---|---|
| ***PT-DE_S1*** | 2394 | 2394 | 25 | 2125,65 |
| ***PT-DE_S2*** | 2744,30 | 1940,52 | 58 | **1184,53** |
| ***PT-DE_S3*** | 2770,14 | 1415,78 | 85 | 1685,15 |
| ***PT-DE_S4*** | 2826,01 | 2571,71 | 129 | 1311,35 |

The scenario with the longest route being done in maritime mode. which leads to a low number of $CO_2$ emissions compared to, for example, the road mode. In terms of costs, it is no longer so attractive because the combination of sea mode and the rail mode were considered, and even for the road mode that showed the higher value than the other scenarios that only combine 2 modes of transport. Regarding the number of kilometres, PT-DE_S4 is higher than the other scenarios since it is necessary to create a route that can include the 3 modes. For the time needed for the transport, it is normal that it will be necessary for around 7 days because PT-DE_S2 the modes chosen are slower transport and where there is a possibility of more delays or even accidents. So, the results showed that PT-DE_S2 was considered as the most successful scenario for the Penamaior (PT) - Erfurt (DE) route.

### 4.3 Tábua (PT) – Piacenza (IT)

For this route, Tábua (PT) - Piacenza (IT), the results from the platform showed that in terms of time and number of kilometres, PT-IT_S1 was positively evaluated. In terms of cost, the most effective scenario is PT-IT_S3, for the case of $CO_2$ emissions, PT-IT_S2 would be the best choice.

*Table 5: Results for Tábua (PT) - Piacenza (IT)- PT-IT_S1 -S4*

| | ***Distance (Km)*** | ***Cost (€)*** | ***Time (unit)*** | ***$CO_2$ Emission (KgCO2)*** |
|---|---|---|---|---|
| ***PT-IT_S1*** | 1915 | 1915 | 22 | 1700,35 |
| ***PT-IT_S2*** | 3187,69 | 1646,91 | 79 | **1006,89** |
| ***PT-IT_S3*** | 2201,12 | 801,53 | 54 | 1194,55 |
| ***PT-IT_S4*** | 3456,07 | 1964,27 | 77 | 1113,13 |

Regarding PT-IT_S4, which is the scenario that does not fit the effectiveness of any of the variables, results presented in Table 5 shows that this scenario is the longest in terms of the time it takes to transport from the beginning to the destination. Regarding $CO_2$ emissions, PT-IT_S4 ranks second place with a slight difference from scenario 3, a difference of 81.42Kg $CO_2$. This difference is due to the fact that, for this scenario, the marine mode has been combined with the railway in the part of the route with greater kilometres, in order to cause less emissions since the more kilometers the more emissions Finally, in terms of costs, this was the scenario with the highest cost, as freight to Italy by sea is high and the remaining costs are also high. For this route, the results showed that from Tábua (PT) - Piacenza (IT), the intermodality scenario that emits the lowest $CO_2$ content is PT-IT_S2.

## 5 CONCLUSIONS

In this research, results from the literature showed Intermodality transport have appeared as an option to support companies on delivering goods reducing their carbon footprint. This work used a case study to illustrate the role of Intermodality on reducing $CO_2$ and contributing to a sustainable transportation. In this way, three routes were selected, and IKEA company was used as a case study, the were considered as source to study four different scenarios.

The scenarios were analysed resorting to DHL Carbon Calculator platform, to calculate the kilometers and the $CO_2$ content emitted. From the application the results were able to determine

the ideal scenario for each route. The evaluation of the remaining variables also allowed us to draw conclusions regarding the choice of the best scenario. For example, the cost of transport increase with the growth in the number of kilometres and also if we combine several types of transport modes. The evaluation of the remaining variables also allowed us to draw conclusions regarding the choice of the best scenario. For example, the cost of transport increase with the growth in the number of kilometres and also if we combine several types of transport modes. The results showed that in terms of emissions scenario 2 was considered the best option for route PT-S. For the case of route PT-DE scenario 2 is the one that has lower emissions and finally, for route PT-IT the best option is scenario 2.

Is important to highlight that the emissions are directed related to the load weight and number of mileages travelled. Yet, this research calls attention for importance of using the concept of intramodality as a particular and relevant strategy in supporting companies in the transition for a sustainable transport. Regardless the potential contribution of this research, some limitation needs to be highlighted, such as the difficulty for assessing availability and schedules if transports used as sample and the need for a detailed economic cost analysis for $CO_2$ emissions. Despite being a simple approach, the results achieved here could offer an important lesson for companies, logistics operators and local governments on developing strategies to support companies in this transition.

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