OPTIMIZING THE CHOICE OF MEANS OF TRANSPORT USING OPERATIONAL RESEARCH

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Resume
This study focuses on the issue of choosing a means of transport on the Pila-Warsaw route by four groups of recipients. Representative sample consists of a student, a family with two children, a business client and a pensioner. The choice of the means of transport depends on various criteria resulting from the preferences of the users of the means of transport. The following criteria emerged from the survey results as a priority: transport time, transport cost, comfort and safety of travel, availability of means of transport, necessity or absence of transfers, cost of luggage transport and punctuality of means of transport. Selected preferences were assigned weightings based on the evaluation of a panel of experts in the field of expertise. In order to select the means of transport to implement the transport task, multi-criteria optimization method was used.

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1 Introduction

Due to the rapid development of civilization, more and more people use private cars to quickly reach their destination, which is mainly work or school [1]. Over the last 10 years, the number of registered cars in Poland has increased by nearly 50% (Figure 1) [2]. Efficient and fast communication is very important due to the ability to easily change position and move from place to place in a short time. Many elements affect efficient communication. One of them is a means of transport adapted to our needs [3-4].

Effective communication with users depends on their activity. Within which one can distinguish their professional, social, existential, physical and other activity. The activity of the inhabitants depends, among other things, on the size of the city. One can meet other activities in the city and with others in the city. Various activities of the inhabitants influence their directions of mobility.

Mobility is defined differently by the authors of the publication. Szoltysek [6] treats mobility as a daily routine movement and activities resulting from the reorganization of personal life, which may include changing the place of residence or work. It can be equated with the movement and all the human activities performed by means of transport outside the place of residence [7-8]. On the other hand, Menes [9] presents mobility as mobility related to the daily movement of residents, mainly to work or school. The issue of mobility was also addressed in [10]. The author showed that the inhabitants of Poland mainly use the car, but quite often choose an active lifestyle, such as cycling or walking.

The mobility of residents depends, among others, on the road and rail infrastructure. The aim of the continuous expansion of road infrastructure is theoretically to reduce the traffic congestion and to adapt to the growing number of vehicles [11]. In addition, improving the road infrastructure may generate an increase in the level of motorization in the medium and long term, which in turn may lead to a new congestion [12].

The demand for travel is a product of individual human needs, for which each person decides to travel based on several factors. These individual decisions are complex and sometimes extremely difficult to define, as they involve many decisions about the destination, frequency and duration of the trip, the time of day the trip takes place, the destination and the chosen method of travel [13]. Moreover, these choices must be seen in the context of simultaneous choices, regarding car ownership, housing location, travel reason and end-of-journey activities [14]. This type of transport in the selection process is influenced by a number of factors directly and indirectly related to a number of decisions of an individual, which can be divided into three large groups: inherent characteristics of a person, route

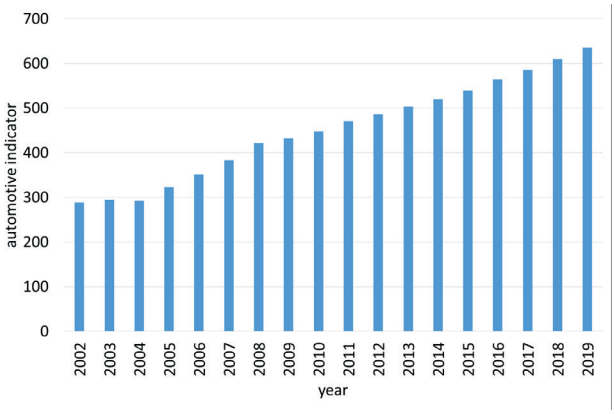

Figure 1 *Automotive index in 2002 ÷ 2019 [1,5]*

Figure 2 *Location of the city of Pila on the map of Poland [20]*

features and characteristics of the means of transport [15-16].

The cost of different modes of transport has been identified as one of the main determinants of the modal choice, along with the inherent time cost of each; The transport demand fluctuates with the time of day, with significant differences between peak and off-peak hours [16]; traffic congestion is a factor to consider and charges are generally higher [15]. In addition, when it comes to the financial costs of travel, aspects such as speed, privacy, personal taste, security and flexibility may play a role [17-18].

According to statistical data, 38 million people live in Poland. Pila is a city located in northwestern Poland in the Greater Poland Voivodeship (Figure 2). Currently, it has about 70000 inhabitants and its area is 102.68 km² [19-20]. The location of the city on the map of Poland is presented below [21-22]. Many residents move to the capital of Poland - Warsaw to rest, visit and it is related to business. They can choose a car, train, bus, or plane for this purpose. The question is which of these modes of transport is the best according to different criteria. The study specifies the method of choosing the means of transport by the inhabitants of Pila.

2 Method

Formulating the optimization task, as presented in studies [23-25], it is difficult to define one scalar quality function F, since acceptable solutions X can have many different properties whose values testify to the quality of the solution. Hence the need to formulate a multi-criteria optimization task with N quality indicators in the form of the F criterion function, which assigns it's a numerical assessment, in the form of the vector $F(x)$, to each acceptable solution $x \in X$, [26]. In the case of multi-criteria optimization, if there is a set of acceptable solutions $x_i \in X$ and there is a set of criteria $f_i \in F$ and a set of criteria dominated by f_i dominance relation $\Phi_i \in \Phi$, the optimization task is implemented according to the following algorithm [27-29]:

1. Normalization of the criterion space (space D^*),
2. Determining the coordinates of an ideal point d^{**},
3. Calculation of the norm value $|\cdot|$ with the parameter $p = 2$ (norm $|\cdot|$ is a measure of the distance of the results $d^* \in D^*$ from the ideal point d^{**} (r_i (D^*)),
4. Determining the optimal result x^o (e.g. $x^o = x_2$ it means that the object x_2 is the best according to the criterion function F).

3 Results

The decisive problem is the choice of means of transport on the route under consideration: Pila (center) - Warsaw (center), for the following groups of passengers:

- Family (two adults and two children, one of them up to 2 years old),
- Business customer,
- Student,
- Older person - pensioner.

The algorithm for obtaining the optimal means of transport for individual groups in accordance with studies [28-29] includes the following stages:

1. Determination of the set of acceptable solutions $x \in X$,
2. Determination of the criterion function for each area of action F,
3. Determination of the solutions of local optimization tasks, according to the "ideal point" method for each passenger group,
4. Determination of the global solution elements of the optimal solution.

The solution scheme for the optimization task of

Table 1 *Dominance relations* Φ

criterion / group of passengers	family	business customer	student	elderly person - pensioner
f_1 - travel time	min	min	min	min
f_2 - travel costs	min	min	min	min
f_3 - travel comfort	max	max	max	max
f_4 - travel safety	max	max	max	max
f_5 - availability of means of transport	max	max	max	max
f_6 - no transfers	min	min	min	min
f_7 - luggage costs	min	min	min	min
f_8 - punctuality of the means of transport	max	max	max	max

determining the optimal means of transport is proposed to be implemented according to the algorithm presented above, i.e.

1. Normalization of criterion space,
2. Determining the coordinates of an ideal point,
3. Calculation of the standard value $|\bullet|$ with the parameter $p = 2$,
4. Determining the optimal result x^o in the optimization task,

As a result, optimal solutions are obtained with specific weight values w_j depending on the distance $r_i(D^*)$.

The algorithmizing scheme for choosing the appropriate way of travel includes the stages, they are:

1. Determining the set of acceptable solutions X,
2. Determination of the criterion function F together with the dominance relation Φ,
3. Determining the optimal x^o solution.

4 Setting of acceptable solution

Firstly, acceptable X solutions are determined, including travel by one or more modes of transport. The set of acceptable solutions X then takes the form:

x_1 - car Pila - Warsaw
x_2 - Pila - Warsaw bus
x_3 - Pila - Warsaw train
x_4 - car Pila - Poznan, plane Poznan - Warsaw
x_5 - bus Pila - Poznan, plane Poznan - Warsaw
x_6 - Pila - Poznan train, Poznan - Warsaw plane
x_7 - car Pila - Poznan, train Poznan - Warsaw
x_8 - car Pila - Poznan, bus Poznan - Warsaw
x_9 - Pila - Poznan bus, Poznan - Warsaw train
x_{10} - Pila - Poznan train, Poznan - Warsaw bus

5 Determination of the criterion function

Passengers have different requirements for choosing the right means of transport, hence its selection depends on many criteria, which include transport costs, route, comfort, etc. In this case, the individual preferences of the passenger and his needs should also be taken into account, which should be met during the trip. These differences consist in different evaluation of criteria, e.g. depending on age, social groups or other preferences. For one of the groups safety may be the most important, for another the costs of transport. In this case, the passenger has the option of choosing a means of transport that will meet all or his most important expectations. The individual requirements are listed as elements of the criterion function, whose values will be different for each set of allowable solutions X. The criterion function F takes the form:

f_1 - travel time,
f_2 - travel costs,
f_3 - travel comfort,
f_4 - travel safety,
f_5 - availability of means of transport,
f_6 - no transfers,
f_7 - luggage cost,
f_8 - punctuality of the means of transport.

The algorithm presented at this stage is related to formulation and solution of the optimization task $< X, F, \Phi >$ for the choice of the means of transport.

Based on the above findings, determining the value of the criteria $f_j \in F$ is possible by calculating their values based on data obtained during the tests or by adopting them based on the expert knowledge. In developing the value of criteria for various acceptable solutions $x_j \in X$, values of criteria $f_j \in F$ and dominance relations Φ were adopted according to the second possibility [28-34] enriched with surveys. For the issues in question, depending on the groups of passengers, a different dominance relationship was adopted - Table 1.

Taking into account the dominance relations, a ranking of criteria for individual groups of passengers can be determined. The ranking of criteria was also corrected by means of surveys in 2020, which were preceded by a pre-test.

Based on Table 2, it can be concluded that for all the established user groups the most important are the travel time and safety. The least important, however, is the size of the luggage and the lack of transfers. The

Table 2 *Ranking of criteria for the considered groups of passengers*

family	business customer	student	elderly person - pensioner
travel time	travel time	travel time	travel time
travel safety	availability of means of transport	the costs of travel	travel safety
travel comfort	travel safety	availability of means of transport	travel comfort
the costs of travel	travel comfort	travel safety	no transfers
availability of means of transport	punctuality of the means of transport	punctuality of the means of transport	the costs of travel
punctuality of the means of transport	no transfers	travel comfort	punctuality of the means of transport
no transfers	luggage size	luggage size	luggage size
luggage size	the cost of travel	no transfers	availability of means of transport

Table 3 *Time of travel and number of transfers from Pila to Central Warsaw - by various means of transport [35-51]*

a set of acceptable solutions	travel time (h)	umber of transfers
x1 - Pila PKP / PKS car - Central Warsaw	4:32	0
x2 - bus Pila - Warsaw Central	6:44	0
x3 - train Pila - Warsaw Central	5:19-5:30	0
x4 - car Pila - Poznan, plane Poznan - Warsaw	Car Saw-Poznan Lawica 1:42 Airplane Poznan Lawica - Warsaw Okecie 1:00 + 1:00 - check-in Warsaw Okecie - Warsaw Central - city bus 0:20-0:28 Total time: 4:02-4:10	2
x5 - bus Pila - Poznan, plane Poznan - Warsaw	Bus Pila - Poznan Dworzec 1:40-1:52 Poznan Dworzec - Poznan Lawica 0:25-0:34 plane Poznan Lawica - Warsaw Okecie 1:00 + 1:00 - check-in for baggage and luggage Warszawa Okecie - Warsaw Central - city bus 0:20-0:28 Total time: 4:25-4:54	3
x6 - Pila - Poznan train, Poznan - Warsaw plane	Train Pila - Poznan Dworzec 1:21-2:09 Poznan Dworzec - Poznan Lawica 0:25-0:34 plane Poznan Lawica - Warsaw Okecie 1:00 + 1:00 - check-in Warszawa Okecie - Warsaw Central - city bus 0:20-0:28 Total time: 4:06-5:11	3
x7 - car Pila - Poznan, train Poznan - Warsaw	Car Pila-Poznan PKP / PKS 1:53 Train Poznan - Warsaw Central 2:54-6:33 Total time: 4:47-8:26	1
x8 - car Pila - Poznan, bus Poznan - Warsaw	Car Pila-Poznan PKP / PKS 1:53 Poznan PKP / PKS bus - Warsaw West 3:50 - 6:30 West Warsaw - East Warsaw - 0:08 train Total time: 5:51-8:31	2
x9 - Pila - Poznan bus, Poznan - Warsaw train	Bus Pila - Poznan Dworzec 1:40-1:52 Poznan - Central Warsaw train 2:54-6:33 Total time: 4:34-8:25	1
x10 - Pila - Poznan train, Poznan - Warsaw bus	Train Pila - Poznan Dworzec 1:21-2:09 Poznan PKP / PKS bus - Warsaw West 3:50 - 6:30 West Warsaw - East Warsaw - 0:08 train Total time: 5:19-8:47	2

Table 4 *Comparison of the travel costs with different means of transport [€] [35-51]*

a set of acceptable solutions / group of passengers	family	business customer	student	elderly person - pensioner
x1 - Pila PKP / PKS car - Central Warsaw	27	27	27	27
x2 - bus Pila - Warsaw Central	66	19	15	15
x3 - train Pila - Warsaw Central	50	19	9	13
class 1 class 2	38	14	7	10
x4 - car Pila - Poznan, plane Poznan - Warsaw				
economy class without luggage	147-270	54-95	54-95	54-95
economy class with luggage	194-317	70-111	69-110	69- 110
x5 - bus Pila - Poznan, plane Poznan - Warsaw				
economy class without luggage	154-284	51-94	50-93	49-92
economy class with luggage	201-331	67-110	66-108	65-107
x6 - Pila - Poznan train, Poznan - Warsaw plane	163-286	56-97	51-92	51-92
class 1 - economy class without luggage				
class 2 - economy class without luggage	155-282	53-95	49-91	49-91
class 1 - economy class with luggage				
class 2 - economy class with luggage	210-333	71-112	66-107	67-108
	202-329	68-111	65-106	65-107
x7 - car Pila - Poznan, train Poznan - Warsaw				
class 1	54-184	25-51	16-51	20-38
class 2	39-88	19-38	13-22	16-29
x8 - car Pila - Poznan, bus Poznan - Warsaw	42-62	17-26	16-25	17-26
x9 - Pila - Poznan bus, Poznan - Warsaw train				
class 1	54-184	25-51	16-51	20-38
class 2	39-88	19-38	13-22	16-29
x10 - Pila - Poznan train, Poznan - Warsaw bus				
class 1	56-76	18-27	13-22	15-24
class 2	48-71	15-25	12-21	13-23

exception is a business customer for whom the costs of travel are not a problem.

In order to facilitate the assessment of the abovementioned variants, the Tables 3-8 are presented in which individual variants of choices are characterized. The first is travel time and the associated number of transfers by various modes of transport.

Based on Table 3, it can be concluded that the shortest connection time from Pila to Central Warsaw is in the case of traveling to Poznan by car and then using the plane. The disadvantage of this solution is two transfers, in Poznan at the airport and in Warsaw the use of public transport to reach the railway station - Warsaw Central and amounts to 4:02 h. The longest minimum travel time, 6:44 h, occurs on the bus connection from Pila to Warsaw. The journey on the analyzed section can be from 4:02 h to 8:47 h and be without transfers, but it can also have 3 transfers when using the Pila - Poznan train and Poznan - Warsaw plane, where public transport in Poznan and Warsaw should be taken into account to and from the airport.

Noteworthy is the fact that when choosing an airplane, a passenger cannot only take flight time into account. In this case, one should also consider the time for check-in. In the case under consideration, it was assumed that this would be 1 h.

The car is the only means of transport by which one can reach the destination without changing. When choosing other means of transport, one must focus on transfers. In the analyzed case, from the city center to

Table 5 *Travel comfort by various means of transport*

criterion / means of transport	car	bus	train	plane
division into classes	individual passenger sensation	lack	class 1 and 2	none in domestic calls
	1	4	1	4
possibility of eating a meal while driving	yes, but it involves a break	lack	yes, but not on all the trains	yes
	3	4	2	1
air conditioning	in most cars occurs	most buses have one	occurs on some trains	yes
	2	2	3	1
it is possible to use the toilet while driving	no	yes, but not on all the buses	yes	yes
	4	3	1	1
space availability	no booking required	yes, but not on all the buses	yes, but not on all the trains	choosing a seat on the plane is charged extra
	1	2	2	2
the opportunity to rest while driving	yes	yes, depending on other passengers	yes, depending on other passengers	yes, depending on other passengers
	1	2	2	2
available space for 1 passenger	big	small	dependent on the train class	average
	1	4	2	3
sum	13	21	13	14

Warsaw, living outside the city center, one has to get to it using public transport or taxis. Sometimes one can get to the station on foot if one lives near the city center.

Table 4 presents a comparison of the travel costs with different options for choosing means of transport.

Analyzing Table 4, it turned out that the cheapest trip for a family is a car and amounts to 27€ and the most expensive by bus from Pila to Poznan and then by plane with additional luggage, which is reasonable with the family, amounting to 331 €. For the remaining groups studied, the cheapest was the direct train from Pila to Warsaw in class 2 and the most expensive by plane.

In Table 4, discounts for individual groups were considered when calculating travel costs. Thus, in the case of a Stalko bus ride: pensioner: receive 10%, senior 70+: 20%, student under 26: 20%, children under 6: 50%. The following discounts apply to Flixbus buses: 78% - children up to 4 years old who occupy a separate place, 37% - children over 4 years old. For other groups, Flixbus does not provide discounts.

Rail carriers apply statutory concessions, namely 51% discount for students under 26 years of age, children up to 4 years old – 100% discount, children aged 4-24 years – 37%. The above discounts apply only to transportation in Class 2. They do not apply in Class 1.

LOT Polish Airlines offer a 90% discount for infants and children up to 2 years old if they do not occupy a separate seat on the plane. The next discount applies to children aged 2-11 and amounts to 25%.

However, in public transport in Poznan, the Municipal Transport Board introduced the following discounts: a student receives 50%, children under 7 use free communication and children under 23 have a 50% discount. However, a pensioner over 70 uses communication free of charge.

Table 6 *Fatalities and injuries with the participation of individual means of transport [44-45]*

criterion / means of transport	car	bus	train	plane
number of fatalities	1682	48	31	0
number of injured, including:	22 271	1 153	24	0
number seriously injured	6160	253	15	0
number slightly injured	16111	900	9	0

Table 7 *Number of connections offered during the day [35-51]*

analyzed route	number of connections offered during the day
x_1 - car Pila PKP / PKS - Central Warsaw	100%
x_2 - bus Pila - Warsaw Central	1
x_3 - Pila - Warsaw Central train	3
x_4 - car Pila - Poznan, plane Poznan - Warsaw (6)	6
x_5 - bus Pila - Poznan (4), plane Poznan - Warsaw (6)	4
x_6 - Pila - Poznan train (18), Poznan - Warsaw plane (6)	6
x_7 - Pila car - Poznan, Poznan - Warsaw train (14)	14
x_8 - car Pila - Poznan, bus Poznan - Warsaw (9)	9
x_9 - Pila - Poznan bus (4), Poznan - Warsaw train (14)	4
x_{10} - Pila - Poznan train (18), Poznan - Warsaw bus (9)	9

In the case of public transport from Warsaw, Warsaw Public Transport has introduced the following discounts: children up to 7 years old free of charge, pupils and students up to 26 years old 50 % and people over 70 years old in Warsaw use public transport for free.

The Table 5 compares the comfort of traveling with different modes of transport. It assumed 6 most common factors that affect the subjective reading of a traveler. The best option was 1 and the worst 4. The means of transport that receives the least number of points can be considered the most comfortable.

Based on Table 5, the subjective assessments of the means of transport selected for analysis were presented in terms of comfort. Based on that, it can be concluded that a passenger car and a train turned out to be the most comfortable, in class 1. The bus was considered the least comfortable.

Another of the criteria discussed is the safety of means of transport. Data from 2019 were analyzed. Based on that, it can be concluded that the majority of the road incidents in the analyzed period were involving passenger cars, 324301 and buses 7922. Similarly, the largest number of road incidents were involving a car and buses, the same number of fatalities and injuries is recorded for these means of transport. The safest means of transport turned out to be an airplane in which there were no fatalities and injuries followed by train, bus. A passenger car turned out to be the least safe means of transport and the results differ significantly with respect to other means of transport. The data is presented in the Table 6.

Then the availability of a given means of transport was determined by checking the number of connections offered during the day on the tested section. The availability of the car as an individual means of transport was assumed as the maximum (100 %), since the passengers have the option of using it whenever they want. In addition to the car, the largest number of connections offered during the day, when connecting the car on the Pila - Poznan route and the Poznan Glówna - Warsaw Central train.

The number in brackets is the maximum number of connections per transport method. In addition, the field “L number of connections offered during the day “ does not include public transport, which runs very often and the train Warszawa Zachodnia - Warszawa Centralna, which is practically every now and then. These data are presented in Table 7.

Luggage size was also analyzed (Table 8). In this case, it was assumed that the traveler would carry a large suitcase measuring 690 x 440 x 250 mm, weight 20 kg. In all analyzed means of transport, the traveler can transport a suitcase for free, except for the plane, for which he must pay 15 € for each suitcase.

In the analyzed sets of acceptable solutions, the fee will be added in the following cases:

- x_4 - car Pila - Poznan, plane Poznan - Warsaw
- x_5 - bus Pila - Poznan, plane Poznan - Warsaw
- x_6 - Pila - Poznan train, Poznan - Warsaw plane

The punctuality of the means of transport in 2019 was also considered. A car is characterized by the greatest punctuality. It was assumed at 98 %, because there are unforeseen situations on the road, such as accidents or congestions, which extend the travel time.

The next punctual means of transport is the train. Based on the data published by the Office of Rail

Table 8 *Fee amount [27-43]*

type of transport	fee amount
car	without payments
train	without payments
bus	without payments
plane	hand luggage (1x 8 kg) - no fee checked baggage (1x 23 kg) - additional fee 15 €.
city transport board in Poznan	without payments
Warsaw public transport	without payments

Table 9 *Criteria values together with the dominance relation Φ for the Family - class 2 group with luggage on the plane*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	F
f_1	272	404	319	242	265	246	287	351	274	319	min
f_2	120	297.50	170.95	872.39	905.06	907.24	176.19	190.94	176.19	215.69	min
f_3	13	21	13	13.75	15.75	13.75	13	19	15	19	max
f_4	1682	48	31	420.5	12	7.75	443.75	456.5	35.25	43.75	max
f_5	1440	1	3	6	4	6	14	9	4	9	max
f_6	0	0	0	2	3	3	1	2	1	2	min
f_7	0	0	0	70	70	70	0	0	0	0	min
f_8	98	81	92.46	80.75	76.5	79.37	93.85	85.25	89.6	83.87	max

Table 10 *Criteria values together with the dominance relation Φ for the business customer - class 1 group with luggage on the plane*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	F
f_1	272	404	319	242	265	246	287	351	274	319	min
f_2	120	85	85	314.33	300.12	321.13	111.8	75.99	111.8	80.19	min
f_3	13	21	13	13.75	15.75	13.75	13	19	15	19	max
f_4	1682	48	31	420.5	12	7.75	443.75	456.5	35.25	43.75	max
f_5	1440	1	3	6	4	6	14	9	4	9	max
f_6	0	0	0	2	3	3	1	2	1	2	min
f_7	0	0	0	70	70	70	0	0	0	0	min
f_8	98	81	92.46	80.75	76.5	79.37	93.85	85.25	89.6	83.87	max

Table 11 *Criteria values along with the dominance relation Φ for the student - class 2 group with luggage on the plane*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	F
f_1	272	404	319	242	265	246	287	351	274	319	min
f_2	120	68	31.85	312.13	295.42	290.97	58.7	73.85	58.7	52.59	min
f_3	13	21	13	13.75	15.75	13.75	13	19	15	19	max
f_4	1682	48	31	420.5	12	7.75	443.75	456.5	35.25	43.75	max
f_5	1440	1	3	6	4	6	14	9	4	9	max
f_6	0	0	0	2	3	3	1	2	1	2	min
f_7	0	0	0	70	70	70	0	0	0	0	min
f_8	98	81	92.46	80.75	76.5	79.37	93.85	85.25	89.6	83.87	max

Transport data, train punctuality in 2019 was 92.46 %. In this case, it is worth noting that the punctuality threshold is 5 minutes and 59 seconds, which means that a train that is late, e.g. 5 minutes and 58 seconds, is considered punctual [52].

Bus (Flixbus -81 %) and public transport in Poznan (77.5 %) have less punctuality. This is mainly due to the weather conditions, season of the year and road conditions (e.g. road accidents, congestion) [53-54].

The plane has the lowest punctuality of the considered means of transport at the level of 75 %. This is mainly due to the exclusion of Dreamliner aircraft and the lack of airworthiness control in some European countries and renovation works at the Warsaw airport [55-57].

6 Determining the optimal solution

In order to solve the multi-criteria optimization task, a computer program "Multi-criteria optimization task 2017" was developed [27-28], which enables:

a) presentation of the set X_j and selection of elements $x_j \in X_j$;
b) presentation of the set F_j and selection, by the computer program operator, of elements $f_j \in F_j$ and dominance relations $\Phi_j \in \Phi$;
c) data entry according to two options: option 1 - manual data entry ($f_j \in F_j$ values), - option 2 - calculation of $f_j \in F_j$ values) based on data obtained during the experimental or simulation tests.
d) visualization of the optimization task solution (calculations and reporting - Tables 9-16).

Table 12 *Criteria values together with the dominance relation Φ for the group Elder - pensioner - class 2 with luggage on the plane*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	F
f_1	272	404	319	242	265	246	287	351	274	319	min
f_2	120	68	45.5	309.93	290.72	290.78	70.23	74.73	70.23	57.98	min
f_3	13	21	13	13.75	15.75	13.75	13	19	15	19	max
f_4	1682	48	31	420.5	12	7.75	443.75	456.5	35.25	43.75	max
f_5	1440	1	3	6	4	6	14	9	4	9	max
f_6	0	0	0	2	3	3	1	2	1	2	min
f_7	0	0	0	70	70	70	0	0	0	0	min
f_8	98	81	92.46	80.75	76.5	79.37	93.85	85.25	89.6	83.87	max

Table 13 *Visualization of the criteria solution for the Family group - class 2 with luggage in the plane*

f/x	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
f_1	272.00	404.00	319.00	242.00	265.00	246.00	287.00	351.00	274.00	319.00
min (f_1)	242.00									
f_1*	0.89	0.60	0.76	1.00	0.91	0.98	0.84	0.69	0.88	0.76
f_1**	0.60									
f_2	120.00	297.50	170.95	872.39	905.06	907.24	176.19	190.94	176.19	215.69
min (f_2)	120.00									
f_2*	1.00	0.40	0.70	0.14	0.13	0.13	0.68	0.63	0.68	0.56
f_2**	0.13									
f_3	13.00	21.00	13.00	13.75	15.75	13.75	13.00	19.00	15.00	19.00
max (f_3)	21.00									
f_3*	0.62	1.00	0.62	0.65	0.75	0.65	0.62	0.90	0.71	0.90
f_3**	1.00									
f_4	1682.00	48.00	31.00	420.50	12.00	7.75	443.75	456.50	35.25	43.75
max (f_4)	1682.00									
f_4*	1.00	0.03	0.02	0.25	0.01	0.00	0.26	0.27	0.02	0.03
f_4**	1.00									
f_5	1440.00	1.00	3.00	6.00	4.00	6.00	14.00	9.00	4.00	9.00
max (f_5)	1440.00									
f_5*	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01
f_5**	1.00									
f_6	0.00	0.00	0.00	2.00	3.00	3.00	1.00	2.00	1.00	2.00
min (f_6)	0.00									
f_6*	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_6**	0.00									
f_7	0.00	0.00	0.00	70.00	70.00	70.00	0.00	0.00	0.00	0.00
min (f_7)	0.00									
f_7*	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
f_7**	0.00									
f_8	98.00	81.00	92.46	80.75	76.50	79.37	93.85	85.25	89.60	83.87
max (f_8)	98.00									
f_8*	1.00	0.83	0.94	0.82	0.78	0.81	0.96	0.87	0.91	0.86
f_8**	1.00									

Table 14 *Visualization of the criteria solution for a business customer group - class 1 with luggage on the plane*

f/x	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
f_1	272.00	404.00	319.00	242.00	265.00	246.00	287.00	351.00	274.00	319.00
min (f_1)	242.00									
f_1*	0.89	0.60	0.76	1.00	0.91	0.98	0.84	0.69	0.88	0.76
f_1**	0.60									
f_2	120.00	85.00	85.00	314.33	300.12	321.13	111.80	75.99	111.80	80.19
min (f_2)	75.99									
f_2*	0.63	0.89	0.89	0.24	0.25	0.24	0.68	1.00	0.68	0.95
f_2**	0.24									
f_3	13.00	21.00	13.00	13.75	15.75	13.75	13.00	19.00	15.00	19.00
max (f_3)	21.00									
f_3*	0.62	1.00	0.62	0.65	0.75	0.65	0.62	0.90	0.71	0.90
f_3**	1.00									
f_4	1682.00	48.00	31.00	420.50	12.00	7.75	443.75	456.50	35.25	43.75
max (f_4)	1682.00									
f_4*	1.00	0.03	0.02	0.25	0.01	0.00	0.26	0.27	0.02	0.03
f_4**	1.00									
f_5	1440.00	1.00	3.00	6.00	4.00	6.00	14.00	9.00	4.00	9.00
max (f_5)	1440.00									
f_5*	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01
f_5**	1.00									
f_6	0.00	0.00	0.00	2.00	3.00	3.00	1.00	2.00	1.00	2.00
min (f_6)	0.00									
f_6*	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_6**	0.00									
f_7	0.00	0.00	0.00	70.00	70.00	70.00	0.00	0.00	0.00	0.00
min (f_7)	0.00									
f_7*	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
f_7**	0.00									
f_8	98.00	81.00	92.46	80.75	76.50	79.37	93.85	85.25	89.60	83.87
max (f_8)	98.00									
f_8*	1.00	0.83	0.94	0.82	0.78	0.81	0.96	0.87	0.91	0.86
f_8**	1.00									

The results of solution optimization task for $f_j \in F_j$ for all the studied travelers' groups indicate that in order to overcome flights Pila-Warsaw, the optimal solution, according to the criteria adopted, is use of the following means of transport: bus route Pila - Poznan and the aircraft on the route Poznan - Warsaw (Tables 17-20).

7 Discussion

Based on the calculations performed, it can be concluded that the solution to the optimization task for $f_j \in F_j$ for all the studied groups to travel the route from Pila to Warsaw, is to use the following means of transport: a bus on the Pila - Poznan route and an airplane on the Poznan - Warsaw route, assuming the above-mentioned criteria: time, cost, comfort, safety and availability of the means of transport. Taking into account the above assumptions, the next measure for the analyzed group of respondents should be the combination: the Pila - Poznan train, the Poznan - Warsaw plane, the Pila - Poznan car, the Poznan - Warsaw plane. It should be noted here that in solving the optimization problem, the plane appears despite the higher price and the greater number of transfers. The results would be completely different if there was an airport in the analyzed city and one would not have to travel to it 100 km. The least favorable means of transport for families, students and the elderly, was to travel by train to their destination. On the other hand, a business client, taking into account the adopted criteria, mainly due to the convenience and time of travel, should not use the bus to reach his destination.

Table 15 *Visualization of the criteria solution for the student - class 2 group with luggage on the plane*

f/x	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
f_1	272.00	404.00	319.00	242.00	265.00	246.00	287.00	351.00	274.00	319.00
min (f_1)	242.00									
f_1*	0.89	0.60	0.76	1.00	0.91	0.98	0.84	0.69	0.88	0.76
f_1**	0.60									
f_2	120.00	68.00	31.85	312.13	295.42	290.97	58.70	73.85	58.70	52.59
min (f_2)	31.85									
f_2*	0.27	0.47	1.00	0.10	0.11	0.11	0.54	0.43	0.54	0.61
f_2**	0.10									
f_3	13.00	21.00	13.00	13.75	15.75	13.75	13.00	19.00	15.00	19.00
max (f_3)	21.00									
f_3*	0.62	1.00	0.62	0.65	0.75	0.65	0.62	0.90	0.71	0.90
f_3**	1.00									
f_4	1682.00	48.00	31.00	420.50	12.00	7.75	443.75	456.50	35.25	43.75
max (f_4)	1682.00									
f_4*	1.00	0.03	0.02	0.25	0.01	0.00	0.26	0.27	0.02	0.03
f_4**	1.00									
f_5	1440.00	1.00	3.00	6.00	4.00	6.00	14.00	9.00	4.00	9.00
max (f_5)	1440.00									
f_5*	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01
f_5**	1.00									
f_6	0.00	0.00	0.00	2.00	3.00	3.00	1.00	2.00	1.00	2.00
min (f_6)	0.00									
f_6*	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_6**	0.00									
f_7	0.00	0.00	0.00	70.00	70.00	70.00	0.00	0.00	0.00	0.00
min (f_7)	0.00									
f_7*	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
f_7**	0.00									
f_8	98.00	81.00	92.46	80.75	76.50	79.37	93.85	85.25	89.60	83.87
max (f_8)	98.00									
f_8*	1.00	0.83	0.94	0.82	0.78	0.81	0.96	0.87	0.91	0.86
f_8**	1.00									

8 Conclusions

Based on the research presented above, it can be stated that multi-criteria optimization is used in the task of choosing the means of transport on the analyzed route. In the analyzed example, on the Pila - Warsaw route, for all the examined groups (family, business client, student and elderly pensioner) it is reasonable to use two means of transport, namely: a bus on the Pila - Poznan route and an airplane on the Poznan - Warsaw route, despite not having the shortest time, nor the lowest ticket price, nor having too large a daily number of connections, the number of transfers and surcharges for luggage on the plane.

Analysis of results of the numerical experiment of solving the multi-criteria optimization task methodology showed the usefulness of the developed algorithm to determine the appropriate means of transport for carrying out the transport task. The advantage of the presented algorithm is also its universality, which allows it to be used to select elements of areas of operation of the broadly understood transport process.

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Table 16 *Visualization of the criteria solution for the group Elder - pensioner - class 2 with luggage on the plane*

f/x	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
f_1	272.00	404.00	319.00	242.00	265.00	246.00	287.00	351.00	274.00	319.00
min (f_1)	242.00									
f_1*	0.89	0.60	0.76	1.00	0.91	0.98	0.84	0.69	0.88	0.76
f_1**	0.60									
f_2	120.00	68.00	45.50	309.93	290.72	290.78	70.23	74.73	70.23	57.98
min (f_2)	45.50									
f_2*	0.38	0.67	1.00	0.15	0.16	0.16	0.65	0.61	0.65	0.78
f_2**	0.15									
f_3	13.00	21.00	13.00	13.75	15.75	13.75	13.00	19.00	15.00	19.00
max (f_3)	21.00									
f_3*	0.62	1.00	0.62	0.65	0.75	0.65	0.62	0.90	0.71	0.90
f_3**	1.00									
f_4	1682.00	48.00	31.00	420.50	12.00	7.75	443.75	456.50	35.25	43.75
max (f_4)	1682.00									
f_4*	1.00	0.03	0.02	0.25	0.01	0.00	0.26	0.27	0.02	0.03
f_4**	1.00									
f_5	1440.00	1.00	3.00	6.00	4.00	6.00	14.00	9.00	4.00	9.00
max (f_5)	1440.00									
f_5*	1.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01
f_5**	1.00									
f_6	0.00	0.00	0.00	2.00	3.00	3.00	1.00	2.00	1.00	2.00
min (f_6)	0.00									
f_6*	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f_6**	0.00									
f_7	0.00	0.00	0.00	70.00	70.00	70.00	0.00	0.00	0.00	0.00
min (f_7)	0.00									
f_7*	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
f_7**	0.00									
f_8	98.00	81.00	92.46	80.75	76.50	79.37	93.85	85.25	89.60	83.87
max (f_8)	98.00									
f_8*	1.00	0.83	0.94	0.82	0.78	0.81	0.96	0.87	0.91	0.86
f_8**	1.00									

Table 17 *Values of distance r_j and weight values w_i for the Family group*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
r_i	1.7268	2.0507	2.0837	1.4796	1.4225	1.4387	1.8828	1.8760	1.8949	1.8539
w_i	0.1003	0.0982	0.0980	0.1018	0.1022	0.1021	0.0993	0.0993	0.0992	0.0995

Table 18 *Values of distance r_j and weight values w_i for the Business Customer group*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
r_i	1.5447	2.2005	2.1560	1.4929	1.4387	1.4520	1.8823	2.0309	1.8944	2.0063
w_i	0.1016	0.0976	0.0979	0.1019	0.1023	0.1022	0.0996	0.0986	0.0995	0.0988

Table 19 *Values of distance r_j and weight values w_i for the Student group*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
r_i	1.5019	2.0645	2.2021	1.4767	1.4204	1.4368	1.8372	1.8194	1.8496	1.8692
w_i	0.1016	0.0980	0.0971	0.1017	0.1021	0.1020	0.0994	0.0995	0.0994	0.0992

Table 20 *Values of distance r_j and weight values w_i for the group Older person - pensioner*

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}
r_i	1.5109	2.1191	2.2021	1.4804	1.4249	1.4412	1.8710	1.8695	1.8832	1.9347
w_i	0.1016	0.0978	0.0973	0.1018	0.1022	0.1021	0.0994	0.0994	0.0993	0.0990

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