

Combination of different means of parcel deliveries in urban logistics in adverse weather conditions

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Abstract: Purpose. The main purpose of the article is to assess the economic and socio-environmental costs of the urban delivery of small shipments in difficult weather conditions with a combination of different delivery means - a car, a motorcycle, a bicycle and a pedestrian courier.

Methodology. The methodology for determining the integrated costs of urban logistics for small shipments in difficult weather conditions is based on an assessment of the region's synoptic data, statistics on road accidents and congestion levels, as well as on the specific operating conditions of the delivery company.

Results. The result of the work is the cost of combining all-season delivery means with a motorcycle and a bicycle, which can only be used under favorable weather conditions.

The theoretical contribution. The theoretical contribution consists in the presentation of a methodology that makes it possible to estimate the complex costs of a combination of various urban delivery means.

Practical implications. Practical implementation consists in calculating the total costs for the delivery of goods for an online store in Kyiv with various combinations of delivery means, which allows to choose the most successful alternative.

Keywords: city logistics, parcel delivery, bad weather conditions, internal and external costs, combination of different means of delivery.

1. Introduction

Nowadays urban logistics is becoming more and more popular. This may occur due to different reasons, but one of the most important is the growth of e-commerce. E-commerce-related last-mile logistics have a great impact on cities. Recent years have seen sustained growth in e-commerce in most developed countries, a trend that has only been reinforced by the COVID-19 pandemic. But at the same time there are great negative environmental impacts from urban freight transportation to a large extent are derived from the fact that conventionally fuelled vehicles are mainly used for transporting goods. Many countries have implemented regulations aimed at setting high technical parameters for conventionally fueled vehicles in order to reduce their negative impacts, however, in the long term these seem to be insufficient. This, combined with the issue of oil resources depletion, leads to the need to search for alternative forms of delivery transport.

According to (Gevaers et al., 2014) the last mile is currently regarded as one of the more expensive, least efficient and most polluting sections of the entire logistics chain. The last mile, described as the last stretch of a parcel delivery to the final consignee who has to take reception of the goods at home or at a cluster / collection point or at the office, accounts depending on several characteristics, for 13% up to 75% of the total supply chain costs. Related to these high costs are the many inefficiencies in the last mile and the poor environmental performance. Currently, cars and vehicles are dominated as means of urban delivery which generates significant negative effects on the urban environment and directly affect the health of city inhabitants. In view of the growing significance of the issues connected with saving energy resources and promoting environmentally friendly transport systems, solutions based on alternative modes and sources of energy are becoming more and more important. And one of such solutions is usage bicycles, bikes and on-foot courier as alternative delivery modes.

2. Literature review

Urban goods transport is a fundamental component of actual city life. Every day, people consume and use goods of very different types and dimensions (e.g., food, clothes, furniture, books, cars and computers) produced throughout the world. Furthermore, freight transport maintains a set of core relationships within urban areas since a city is an entity where production, distribution and consumption activities are located and use limited land. Moreover, the number of people, who live in cities, grows each year. The reasons for the complication of urban logistics:

1. Today, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050 (World Urbanization Prospects, 2019).
2. Till the 2014 more than 100 million people have migrated to cities globally since 2000 (World urbanization prospects, 2014).
3. By 2050, at least 70% of the world population will live in cities (World urbanization prospects, 2014).
4. In Europe, around 75% of the population lives in urban areas (Degree of urbanization, 2020).
5. Inventories of the Intergovernmental Panel on Climate Change (IPCC) emission quantification methodology, and the creation of scenarios for up to 10 subsequent years, it is possible to verify that individual motorized transport accounts for 60% of the total emissions from the urban transportation sector (Toledo & Rovere, 2018).
6. Urban freight vehicles account for 6 -18% of total urban travel (Study on Urban Freight Transport, 2012) and 19% of energy use and 21% of CO₂ emissions in Europe (Russo & Comi, 2012).
7. Annually, approximately 1% of the Gross Domestic Product of the European economy is lost due to congestion (Haubold, 2016).

According to Pojani and Stead (Pojani & Stead, 2015) cities in developing countries are confronted with a rapid growth in transport-related challenges such as pollution, congestion, accidents, public transport decline, energy deletion and environmental degradation. It necessitated the need for sustainable mobility which sought to ensure the mobility by reorienting transport demand towards safe and more environmentally friendly modes of transport (UNECE Handbook on Sustainable Transport and Urban Planning, 2019, Buhari, 2020, Gambetta & Baric, 2020).

For example, (Tulu et al., 2019) shows the successful experience of expanding the cycling infrastructure, which saves money for the family budget, almost does not participate in the formation of traffic congestion, and has a beneficial effect on the level of urban air quality.

Model for sustainable urban mobility is expected to cover bus rapid transport, light rail, tram, electrification, cycling and walking. Furthermore, some of the essential benefits of adopting sustainable urban mobility to solve the challenges of our increasing urbanization and motorization include the following:

1. Reduction in road congestion.
2. Reduction in travel/journey time.
3. Promotion of safe and convenient means for movement.
4. Reduction in pollution and improved healthier environment.
5. Facilitation of intermodal transport system (Buhari, 2020).

In the urban distribution of goods, the road mode appears to be dominant in urban mobility. However, this trend is changing. European cities are moving towards more sustainable, quiet, healthy, cleaner, smoother mobility with low emission levels, as far as the urban distribution of goods is concerned. The innovative city logistics of zero or low CO₂ emissions can contribute to this goal, particularly in dense urban areas where freight journeys are mostly short.

With the global focus on the environmental aspect, transportation companies in urban areas have been innovating in the search of alternative technologies in the fight against the emission of greenhouse gases and atmospheric pollutants.

So, it is necessary to consider all delivery transport modes to understand situation as a whole, the most popular and commonly used ones are automobile, on-foot, motorcycle and bicycle deliveries.

3. Research methods

Consider the features of using various delivery vehicles for urban package delivery:

- car;
- motorcycle;
- bicycle;
- on-foot courier using public transport.

Car

From the above list, a car is the most studied means of transportation in the city, both in terms of direct and external costs. Other delivery vehicles have been studied much less and require aggregation of acquired knowledge.

This is a very convenient type of transportation because you can deliver orders not only to one point, but collect several orders at once and deliver them to a certain area. The weather conditions have almost no influence on the car, it will be able to leave in the rain and snow, without bringing strong discomfort to the courier. On the other hand, this type of delivery also has its drawbacks. First of all, it is a floating price that depends on fuel prices. Moreover, the driver can simply get stuck in a traffic jam and delay. In this, cars are much inferior to other types of delivery.

Motorcycle

A delivery motorcycle is much more cost-effective than a delivery car. Not only is it cheaper to buy (or hire), but it is also cheaper to run (in terms of fuel costs, insurance and tax), as well as being cheaper to maintain.

Motorcycles make it easier to navigate through congested traffic. While a car would be stopped by the traffic jam, a motorcycle can navigate around the traffic with ease. This makes it more reliable and in turn, more efficient for businesses.

Bicycle

Cycle logistics have the ability to contribute to a cleaner and smoother environment. In addition, cycle logistics has the ability to overcome many of the negative obstacles to the last part of the delivery. Indeed, smaller vehicles do not need many parcels to reach a higher load factor, they do not take up much space when they park, do not pay to park and even on the street itself, helping to lessen the congestion.

Thus, a solution that addresses some important concerns in the transportation of goods in urban areas is cargo cycles, such as bicycles, cargo bikes and cargo tricycles, that can be electric powered or not. The existing literature is still weak and very recent in the diffusion of this innovation.

Cargo cycles are a zero-emission alternative to light goods vehicles in city centres. This paper improves our understanding of how to develop cycle logistics to reduce the adverse impacts of urban goods deliveries without reducing the quality of city living.

Overall, studies find that the use of cargo cycles represent a viable solution for urban freight transport.

For example, Lenz and Riehle (2013) suggest that cycle freight can form around 25% of city center commercial traffic in the medium term and that a potential market does exist. Specific areas of application and markets include courier, express and parcel services and the delivery of basic products in catering, but there is a significant potential for cycle freight to carry out deliveries with small volumes and comparatively low weight (ibid). In terms of decarbonizing the urban logistics sector, a London based case study finds that the total distance travelled and the CO₂e emissions per parcel delivered fell by 20% and 55% respectively as a result of a delivery system utilizing urban consolidation centers and small electric vehicles and cargo tricycles (Allen et al., 2012), while a Dutch study estimated possible annual fuel savings for the Netherlands of 8,500,000 l of diesel, or 21,000 tons of CO₂ (Maes & Vanelslander, 2012).

On-foot delivery

On-foot delivery is an attractive, sustainable way to deliver packages in the city. The courier's travel speed is comparable to the speed of a bicycle in congestion-free conditions, since he can use public transport for part of the route, as it proved in (Galkin et al., 2019). Naturally, the most significant limiting factor for a walking courier is the ability to take a small amount of cargo. That is why the on-foot courier is mainly used for package and postal deliveries in the city.

Further calculations are a continuation of the research of Comi and Savchenko, 2020). In the studies of these authors, presented at the conference Green Cities 2020, as well as in (Savchenko & Donets, 2020, Savchenko, 2020), direct internal and external costs were calculated when using a car, motorcycle, bicycle and on-foot courier in Kyiv. The technique has been tested on an online store that carries out about 100 deliveries per day. For its conditions, the required number of different delivery vehicles is determined (Tab. 1), as well as all components of internal and external costs for urban logistics (Table 2 and 3).

Table 1: Parameters of delivery tour/route along the working shifts

Route Parameter	Unit	1st shift				2nd shift			
		car	moto	bicycle	foot	car	moto	bicycle	foot
Limitation for cargo capacity	unit	133	20	10	6	133	20	10	6
Speed	km/h	30.21	36.77	14.27	15.10	28.10	36.07	14.11	14.05
Number of customers on the route	clients	30.00	20.00	10.00	6.00	30.00	20.00	10.00	6.00
Maximal number of tours/routes per shift	unit	1.01	1.49	1.98	2.74	1.00	1.49	1.98	2.72
Required routes per shift	unit	3.33	5.00	10.00	16.67	3.33	5.00	10.00	16.67
Number of means needed for daily delivery	veh.	1.67	2.50	5.00	8.33	1.67	2.50	5.00	8.33

Source: Comi & Savchenko, 2020

Table 2: Direct internal costs for various types of urban delivery modes

Delivery Mode	Components of Internal Costs [EUR/day]							Total Annual Internal Costs for 1 Means [EUR/year]
	Salary	Amortization	Cost of fuel	Maintenance and Repair	Other Operating Expenses	Other Expenses	Total Internal Costs	
Car	133,33	41,67	354,06	2,78	1,39	26,66	559,89	61186
Motorbike	200,00	16,67	239,11	1,67	0,83	22,91	481,19	35127
Bicycle	300,00	4,17	-	1,67	0,83	15,33	322,00	11753
On foot / Transit	416,67	-	-	-	-	20,83	437,50	9585

Source: Comi & Savchenko, 2020

Table 3: Annual external cost for various types of urban delivery modes

Delivery mode	Annual external cost, euro		
	Accident	Congestion	Pollution
Car	506	9264	250
Motorcycle	64938	3111	413
Bicycle	12747	1235	0
On-foot	497	0	0

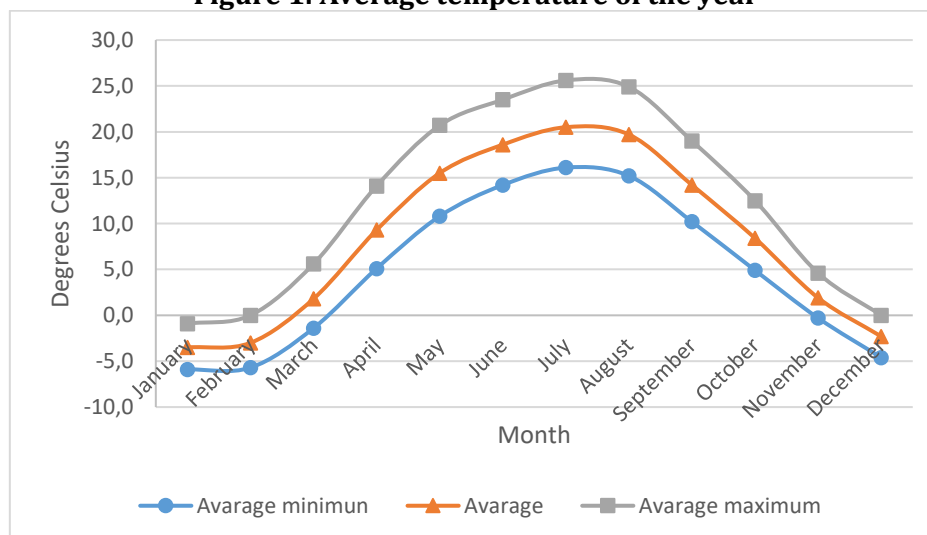
Source: Comi & Savchenko, 2020

Consequently, we can see that the highest rating has on-foot delivery, but it cannot be multifunctional, this delivery mode has a great influence from the human forces and responsibilities. The second one in this rating is bicycle, it is a good solution for delivery services especially in warm days, also it is a fully environmentally-friendly mode of transport. Cars as a delivery mode of transport is on the third place, it is quite clear, as it has huge costs on its maintenance, it has a great bad impact on the ecology. The last one is motorcycle delivery transport mode, as it is also not so eco-friendly as bicycle or on-foot delivery, it cannot be applicable for delivery under all weather conditions.

Influence of weather conditions on choice of delivery mode of transport

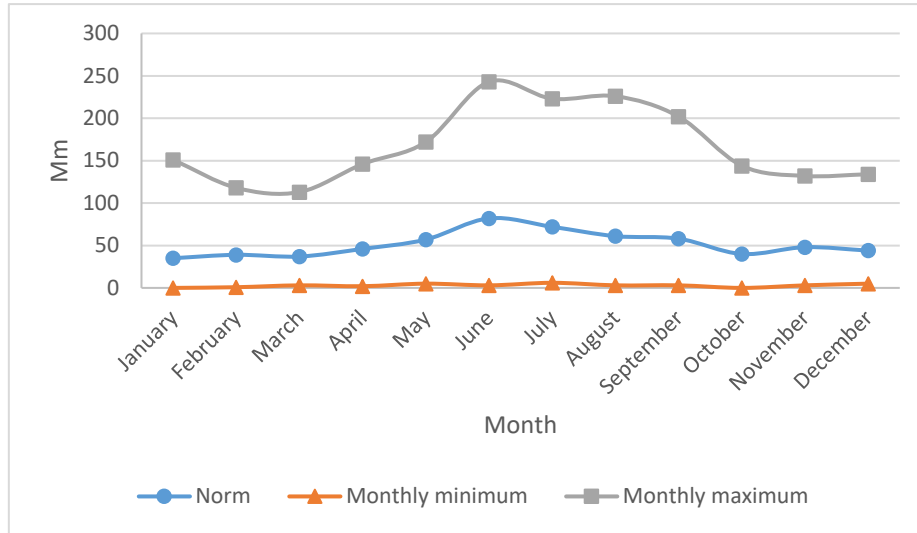
Unfortunately, the use of bicycles and motorcycles, which have a positive effect on the social and ecological situation in the city, is limited in regions with cold, snowy winters, which include Ukraine and Kyiv in particular. What is more, one of the most important factors in choice of delivery mode of transport is weather.

Let's consider an information about weather conditions and changes during a year in Kyiv (Fig. 1-3).

Figure 1: Average temperature of the year

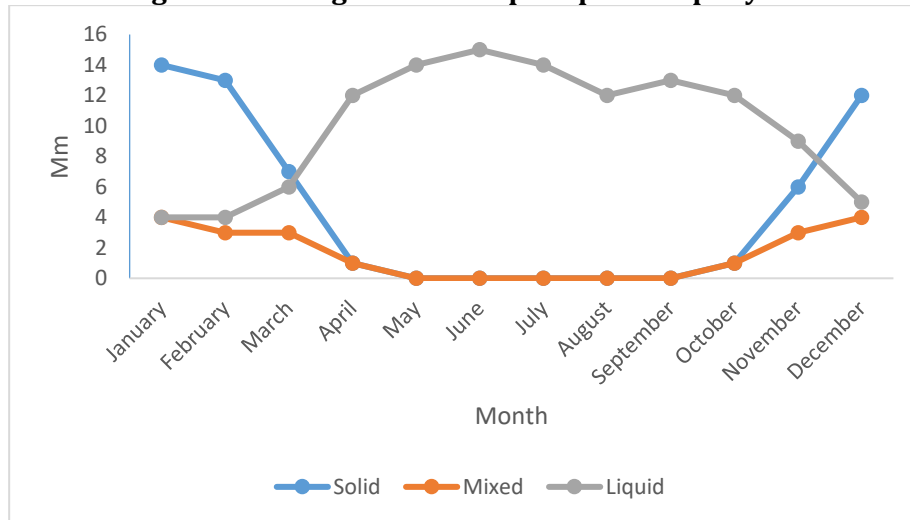
Source: based on (Climate in Kyiv)

Figure 2: Number of downfalls every month per year



Source: based on (Climate in Kyiv)

Figure 3: Average volume of precipitation per year



Source: based on (Climate in Kyiv)

Here we can see that situation with downfalls, especially snow makes it more difficult for bicycles and motorcycles to be competitive in terms of fast and safe delivery. So, there is a need to calculate costs, which are related to different modes of transport in order to be able to make a decision about rational combination of different delivery modes for transportation through all seasons.

Costs calculation for season with difficult weather conditions

Based on the analysis of Fig. 1-3, the number of days per year was determined, during which each type of city delivery can be used. Tab. 4 indicates the months in which not all means can be used.

Table 4: Average number of working days for season with difficult weather conditions

Delivery mode	Number of Days				
	January	February	March	November	December
Car	31	28	31	30	31
Motorcycle	0	0	15	16	0
Bicycle	0	0	10	9	0
On-foot/transit	31	28	31	30	31

Firstly, it is necessary to determine the internal and external costs in order to calculate the total ones.

Considering that a car and an on-foot courier can be used for city delivery throughout the entire calendar year, the authors have assessed the possibility and feasibility of combining these "universal" delivery modes with a motorcycle and a bicycle during the warmer months. Thus, the following combinations were evaluated:

- 1) car - motorcycle;
- 2) car - bicycle;
- 3) on-foot courier - motorcycle;
- 4) on-foot courier - bicycle.

Table 5 shows numbers of working day for each combination.

Table 5: Numbers of working day for each combination of city delivery modes for season with difficult weather conditions

Delivery mode	Working days				
	January	February	March	November	December
1st combination					
Car	31	28	16	14	31
Motorcycle	0	0	15	16	0
2nd combination					
Car	31	28	21	21	31
Bicycle	0	0	10	9	0
3rd combination					
On-foot	31	28	21	21	31
Bicycle	0	0	10	9	0
4th combination					
On-foot	31	28	16	14	31
Motorcycle	0	0	15	16	0

Table 6-9 shows internal costs for each combination.

Table 6: Internal costs of combination "Car+Motorcycle" for season with difficult weather conditions

Delivery mode	Salary costs per day	January	February	March	November	December
		Salary				
Car	133,33	4133,23	3733,24	2133,28	1866,62	4133,23
Motorcycle	200	0	0	3000	3200	0
Amortization costs per day						
Delivery mode	day	Amortization				
Car	41,67	1291,77	1166,76	666,72	583,38	1291,77
Motorcycle	16,67	0,00	466,76	266,72	233,38	516,77
Cost on fuel per day						
Delivery mode	day	Fuel				
Car	354,06	10975,86	9913,68	5664,96	4956,84	10975,86
Motorcycle	239,11	0,00	0,00	3586,65	3825,76	0,00
Maintenance and Repair costs per day						
Delivery mode	day	Maintenance and Repair				
Car	2,78	86,18	77,84	44,48	38,92	86,18
Motorcycle	1,67	0	0	25,05	26,72	0
Other expenses per day						
Delivery mode	day	Other expenses				
Car	26,66	826,46	746,48	426,56	373,24	826,46
Motorcycle	22,91	0	0	343,65	366,56	0

Table 7: Internal costs of combination "Car+Bicycle" for season with difficult weather conditions

Delivery mode	Salary costs per day	January	February	March	November	December
		Salary				
Car	133,33	4133,23	3733,24	2799,93	2799,93	4133,23
Bicycle	417	0	0	4166,7	3750,03	0
Delivery mode	Amortization costs per day	Amortization				
		January	February	March	November	December
Car	41,67	1291,77	1166,76	875,07	875,07	1291,77
Bicycle	4,17	0,00	0,00	41,70	37,53	0,00
Delivery mode	Cost on fuel per day	Fuel				
		January	February	March	November	December
Car	354,06	10975,86	9913,68	7435,26	7435,26	10975,86
Bicycle	0	0,00	0,00	0,00	0,00	0,00
Delivery mode	Maintenance and Repair costs per day	Maintenance and Repair				
		January	February	March	November	December
Car	2,78	86,18	77,84	58,38	58,38	86,18
Bicycle	1,67	0	0	16,7	15,03	0
Delivery mode	Other expenses per day	Other expenses				
		January	February	March	November	December
Car	26,66	826,46	746,48	559,86	559,86	826,46
Bicycle	23,74	0	0	237,4	213,66	0

Table 8: Internal costs of combination "On-foot+Bicycle" for season with difficult weather conditions

Delivery mode	Salary costs per day	January	February	March	November	December
		Salary				
On-foot	416,67	12916,77	11666,76	8750,07	8750,07	12916,77
Bicycle	417	0	0	4166,7	3750,03	0
Delivery mode	Amortization costs per day	Amortization				
		January	February	March	November	December
On-foot	0,00	0,00	0,00	0,00	0,00	0,00
Bicycle	4,17	0,00	0,00	41,70	37,53	0,00
Delivery mode	Cost on fuel per day	Fuel				
		January	February	March	November	December
On-foot	0,00	0,00	0,00	0,00	0,00	0,00
Bicycle	0	0,00	0,00	0,00	0,00	0,00
Delivery mode	Maintenance and Repair costs per day	Maintenance and Repair				
		January	February	March	November	December
On-foot	0,00	0	0	0	0	0
Bicycle	1,67	0	0	16,7	15,03	0
Delivery mode	Other expenses per day	Other expenses				
		January	February	March	November	December
On-foot	20,83	645,73	583,24	437,43	437,43	645,73
Bicycle	23,74	0	0	237,4	213,66	0

Table 9: Internal costs of combination "On-foot+Motorcycle" for season with difficult weather conditions

Delivery mode	Salary costs per day	January	February	March	November	December
		Salary				
On-foot	416,67	12916,77	11666,76	6666,72	5833,38	12916,77
Motorcycle	200	0	0	3000	3200	0
Delivery mode	Amortization costs per day	Amortization				
		January	February	March	November	December
On-foot	0,00	0,00	0,00	0,00	0,00	0,00
Motorcycle	16,67	0,00	0,00	250,05	266,72	0,00
Delivery mode	Cost on fuel per day	Fuel				
		January	February	March	November	December
On-foot	0,00	0,00	0,00	0,00	0,00	0,00
Motorcycle	239,11	0,00	0,00	3586,65	3825,76	0,00
Delivery mode	Maintenance and Repair costs per day	Maintenance and Repair				
		January	February	March	November	December
On-foot	0,00	0	0	0	0	0
Motorcycle	1,67	0	0	25,05	26,72	0
Delivery mode	Other expenses per day	Other expenses				
		January	February	March	November	December
On-foot	20,83	645,73	583,24	333,28	291,62	645,73
Motorcycle	22,91	0	0	343,65	366,56	0

Table 10-13 shows external costs for each combination.

Table 10: External costs of combination "Car+Motorcycle" for season with difficult weather conditions

Delivery mode	Pollution costs per day	January	February	March	November	December
		Pollution				
Car	2,3	70,9	64,1	36,6	32,0	70,9
Motorcycle	5,7	0,0	0,0	84,9	90,5	0,0
Delivery mode	Congestion costs per day	Congestion				
		Car	84,8	2627,9	2373,6	1356,4
Motorcycle	42,6	0,0	0,0	639,2	681,9	0,0
Delivery mode	Accidents costs per day	Accidents				
		Car	4,6	143,5	129,6	74,1
Motorcycle	889,6	0,0	0,0	13343,4	14233,0	0,0

Table 11: External costs of combination "Car+Bicycle" for season with difficult weather conditions

Delivery mode	Pollution costs per day	January	February	March	November	December
		Pollution				
Car	2,29	70,92	64,05	48,04	48,04	70,92
Bicycle	0,00	0,00	0,00	0,00	0,00	0,00
Delivery mode	Congestion costs per day	Congestion				
		Car	84,77	2627,93	2373,61	1780,21
Bicycle	33,84	0,00	0,00	338,36	304,52	0,00
Delivery mode	Accidents costs per day	Accidents				
		Car	4,63	143,54	129,65	97,24
Bicycle	349,23	0,00	0,00	3492,33	3143,10	0,00

Table 12: External costs of combination "On-foot+Motorcycle" for season with difficult weather conditions

Delivery mode	Pollution costs per day	January	February	March	November	December
		Pollution				
On-foot	0,00	0,00	0,00	0,00	0,00	0,00
Motorcycle	5,66	0,00	0,00	84,86	90,52	0,00
Delivery mode	Congestion costs per day	Congestion				
		On-foot	0,00	0,00	0,00	0,00
Motorcycle	42,62	0,00	0,00	639,25	681,86	0,00
Delivery mode	Accidents costs per day	Accidents				
		On-foot	22,68	703,23	635,18	362,96
Motorcycle	889,56	0,00	0,00	13343,42	14232,99	0,00

Table 13: External costs of combination "On-foot+Bicycle" for season with difficult weather conditions

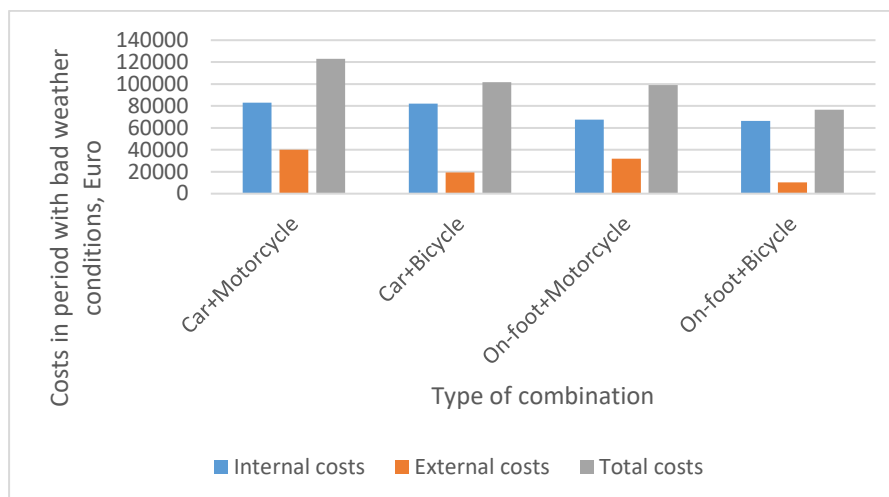
Delivery mode	Pollution costs per day	January	February	March	November	December
		Pollution				
On-foot	0,00	0,00	0,00	0,00	0,00	0,00
Bicycle	0,00	0,00	0,00	0,00	0,00	0,00
Delivery mode	Congestion costs per day	Congestion				
		On-foot	0,00	0,00	0,00	0,00
Bicycle	33,84	0,00	0,00	338,36	304,52	0,00
Delivery mode	Accidents costs per day	Accidents				
		On-foot	22,68	703,23	635,18	476,38
Bicycle	349,23	0,00	0,00	3492,33	3143,10	0,00

In order to evaluate the total costs of the various cost components, it is necessary to calculate the sum for each of the four types of combinations.

4. Research results and discussion

The results of calculating the costs of various combinations of urban delivery modes are presented in Fig. 4.

Figure 4: Internal, external and total costs of various combinations of urban delivery modes



In addition, a rating of various combinations (1 - excellent, 4 - poor) was obtained for internal, external and general urban delivery costs (Tab. 14).

Table 14: Rating of internal, external and total costs of different combination of means of urban delivery in bad weather conditions

Delivery mode	Internal costs rating	External costs rating	Total costs rating
Car+Motorcycle	4	4	4
Car+Bicycle	3	2	3
On-foot+Motorcycle	2	3	2
On-foot+Bicycle	1	1	1

The best combination according to all components of the total cost is "On-foot+Bicycle". Such alternative shows the lowest direct cost for urban delivery and is the most environmentally friendly.

It should be added that the results were obtained for specific conditions and cannot be applied to any urban delivery situation. However, the technique outlined in the article allows one to obtain cost estimates for a specific case.

Conclusions

So, there is a necessity to use collaborative means of urban delivery during the year. It is impossible to use bicycle or motorcycle for the whole year, as it is quite uncomfortable and unsuitable for the bad weather conditions, while these modes of delivery are eco-friendly and economical. The combination of different transport modes is applicable as the solution of this issue.

It is much more profitable for logistics companies or shippers to use a combination of delivery models, rather than preferring anyone. While the courier delivers the order within walking distance, the motorcycle will already be able to deliver several orders. As discussed earlier, bicycles and motorcycles have their drawbacks, namely that amortization must be paid during all the year, while these modes are unusable in bad weather conditions, which affects overall costs. Despite the fact that the company cannot use them in bad weather conditions, it can use the car or on-foot delivery, and when the weather improves, may turn to the help of a bicycle or motorcycle.

Therefore, it is needed to be considered that the impact of all types of costs and choose the appropriate option in order to compose the most convenient combination of deliveries to use with the lowest costs.

Citation information

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