Reducing the Negative Impact of Harmful Factors on the Environment in the Process of Transporting Waste from Demolition of Buildings and Structures

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Abstract. The relevance of the problem under study is due to the fact that in the process of transporting demolition waste, it becomes necessary to reduce the negative impact of harmful factors on the environment. The aim of the study is to reduce the negative impact on the environment during transportation and to select optimal solutions. As a result of the study, the factors influencing the formation of the transport chain were identified, which reduce the negative impact of some harmful factors on the environment during the transportation of construction waste. Also, as a result of simulation, optimal combinations of important factors were formed in the conditions of urban infrastructure, which made it possible to reduce the estimated indicators of harmful effects on the environment.

1. Introduction
The active development of transport construction leads to the emergence of problems of storage, transportation, burial or disposal of construction and demolition waste.

Human activities inevitably cause damage to the environment, this damage cannot be reduced to zero, but its magnitude lends itself to management and regulation.

One of the most difficult problems of environmental protection and preservation of ecological balance is the problem of managing the processes of disposal and removal of waste to the places of disposal or recycling [1-6].

The problem of waste is especially relevant for large cities and urban agglomerations, in which industrial enterprises, service enterprises are concentrated, large masses of people are concentrated in relatively small areas. The ecological well-being of such cities and agglomerations depends on many factors.

The rapid generation of construction and demolition waste has recently become a matter of concern. From 1.3 to 1.7 billion tons of waste are generated annually in different parts of the world. Of these, 15-22%, that is ~ 0.374 billion tons, are demolition products.

According to statistics obtained by statistical agencies, approximately 6 million tons of construction and demolition waste are generated annually. Most of them are waste concrete and reinforced concrete. According to forecasts of the same statistical agencies, the rate of formation of volumes of construction and demolition waste and concrete scrap in the near future will increase to 15–17 million tons/year. The...
main source of construction and demolition waste generation is the production of building materials, parts, structures, construction, dismantling or demolition of buildings and structures.

One of the problems of urban agglomeration today is the problem of demolition or dismantling of buildings in dense urban development, as well as further transportation of the generated construction and demolition waste to storage, recycling or burial sites. This problem arises in connection with an intensive program of housing renovation in many cities of Russia. This problem is especially relevant in large cities, such as St. Petersburg and Moscow, in which problems have already arisen in connection with the introduction of the housing renovation program [7-13].

When transporting construction and demolition waste, a fairly large amount of harmful substances (construction dust, CO₂, etc.) gets into the environment. The aim of the work is to reduce the level of harmful factors on the environment by optimizing the methods for generating construction waste and optimizing the options for choosing vehicles for their transportation.

2. Material and methods
The object of research in this work is the negative impact (harmful factors) on the environment in the transportation process of construction and demolition waste. The subject of the research is to study the possibility of reducing the negative impact on the environment during the transportation of construction waste. The following methods were used in the work: methods of mathematical modeling of processes (statistical decisions, analysis, "playing with nature"), empirical methods of collecting information and data, mathematical modeling, methods of machine imitation.

3. Research results
In accordance with the methods and ways of demolition/dismantling of buildings and structures, the legislative framework of the Russian Federation and regulatory documents for the transportation of goods of IV and V hazard classes, which include construction and demolition waste, there are no special instructions for transportation conditions. But special conditions apply to vehicles, to their environmental safety class. As a result of this inconsistency, a contradiction arises.

To make the best decisions in the field of collection and transportation of construction and demolition waste, it is necessary to choose the best way to dismantle or demolition of a building (Table 1).

Table 1. Scheme of methods of formation and ways of removal of construction and demolition waste.

| The choice of the way/method of demolition/dismantling of the building, depending on the density of urban development | Action | Result of simulation |
| --- | --- | --- |
| Way/method of demolition/dismantling of a building | Mechanical | Demolition/Dismantling | Probability of demolition waste generation at the facility | $P = 0.7 \div 0.9$ |
| Manual | $V_{drive} \sim V_{designed 
 volumes}$ | | |
| Combined | | | |

Choosing a way for removal of demolition waste from the place of their formation, taking into account the infrastructure of the city

| Way of removal of construction and demolition waste | Action | Result of simulation |
| --- | --- | --- |
| Bulk | Choosing the type of container, taking into account the carrying capacity of road transport and the infrastructure of the city | Probability of reliability of removal of demolition waste from the facility | $P = 0.7 \div 0.9$ |
| Containers | | | |
When forming a scheme for the removal of construction and demolition waste using mathematical modeling, many factors are taken into account that affect the environment both when loading the generated waste onto vehicles and during transportation to the place of recycling or disposal.

When choosing the volume of a container and a vehicle, important factors are taken into account, such as:

- the infrastructure of the facility/territory – the passage of large-sized vehicles without a special permit is prohibited within the city limits, and the passage of heavy-duty vehicles is also prohibited;
- the time of work with an increased noise level – in St. Petersburg, according to the law on "Silence", all construction and noisy work is carried out from 8 to 22 hours, also work on the dismantling/demolition of the object cannot be carried out on weekends and holidays;
- the environmental load on the territory of the demolition site and the road chain for the removal of construction waste – closed containers during transportation minimize the load on the environment, since the dust from construction waste on the route of road transport does not exceed the permissible limit values;
- the kind and type of fuel for vehicles also plays an important role when choosing a vehicle – the higher the environmental safety class, the lower the level of environmental pollution during transportation of construction and demolition waste;
- the carrying capacity of vehicles is determined in accordance with road requirements – as noted above, in the conditions of urban road infrastructure, a number of restrictions are imposed on the weight and carrying capacity of vehicles and their overall dimensions;
- the volume of construction containers should not exceed 32 m³, the most common container volume is 27 m³, which is installed on any type of vehicles intended for the export of containers. Containers with a volume of 20 m³ can also be used, but only in cases where there is an extremely dense development of buildings and it is not possible to use containers of a larger volume and, accordingly, cars of large size and carrying capacity, for example, in the historical part of the city of St. Petersburg (Table 2).

Table 2. Vehicles and containers for transportation of construction and demolition waste (using the example of urban development in St. Petersburg, the table is given in the abbreviation).

| Containers          | Volume, m³ | Overall dimensions (L×W×H), mm | Weight, kg |
|---------------------|------------|-------------------------------|------------|
| Swap body trucks    |            |                               |            |
| Car brand           |            |                               |            |
| Model               | KAMAZ MSK-16-01 (MSSO-01) (with swap body lifter) | VOLVO FH12 | VOLVO F12 |
| Carrying capacity   | 15450      |                               | 30000      | 13000      |
| of the chassis      | 15450      |                               | 30000      | 13000      |
| with platform       | 15450      |                               | 30000      | 13000      |
| mechanism, kg       |            |                               | 7200       |            |
| Environmental class | 4          |                               | Euro-3     | Euro-3     |
| Vehicle weight, kg  |            |                               | 8500       |            |
| curb                | 9600       |                               | 8500       |            |
| full                | 25200      |                               | 18200      |            |
| Overall dimensions  | 7660×2500×2870 | 5887×2495×3906 | 2400×2480×3428 |
| of the vehicle      | (L×W×H), mm |                               |            |            |
|                     |            |                               |            |            |
As a result of the choice of a vehicle with optimal technical requirements, an increase in the environmental safety class of vehicles (in particular, fuel brands), the atmospheric pollution index decreases from 11 to 4. This happens due to the use of vehicles that are optimal for specific conditions (the result of simulation modeling of the formation of an optimal transport chain removal of construction waste from the facility under specified conditions and a level of reliability).

For a complete picture, it is also necessary to take into account the transportation time, which includes the loading and unloading of construction and demolition waste. The calculation of the economic efficiency of various schemes for the removal of construction and demolition waste is presented in Tables 3 and 4.

**Table 3.** Data required for calculating funds for fuel by options (the table is given in the abbreviation).

| Car/ container (fluff) | Volume, m³ | Carrying capacity, t | Time for loading, h | Price (rub) per trip | Price (rub) Hour* | Price (rub) Km* |
|-----------------------|------------|---------------------|--------------------|---------------------|------------------|-----------------|
| GAZelle               |            | 1.5                 | 2                  | 2200                | 1800             | 500             |
| ZIL-dump truck        | 5-6.5      | 5                   | 2                  | 2600                | 2500             | 500             |
| KAMAZ-dump truck      | 8-10       | 10                  | 2                  | 3600                | 3600             | 700             |
| Container 6 m³        | 6          | 3                   | 2                  | 2600-2700           | 2500-2600        | 100             |
| Container 12 m³       | 12         | 10                  | 6                  | 4500                | 4300             | 100             |
| Container 20-27 m³    | 20-27      | 10                  | 6                  | 5000-5300           | 5000             | 100             |

Note: * In case of idle time for loading over the established time, an hourly surcharge is made.
** When removing outside the city, a round-trip mileage surcharge is required.

**Table 4.** Data on the cost of fuel for refueling vehicles (* Prices are valid for 2016).

| Fuel type | PTK | GazProm | LUKOIL | Phaeton | Shell | Neste | Rosneft | Avg. city price |
|-----------|-----|---------|--------|---------|-------|-------|---------|-----------------|
| DT        | 32.10 | 32.65  | 32.45  | 32.45  | 32.44 | 33.10 | 31.85   | 32.43           |
| A-92      | 28.90 | 29.10  | 30.10  | 29.10  | 29.19 | 28.69 | 28.80   | 29.13           |
| A-95      | 34.96 | 33.89  | 35.96  | 33.50  | 36.00 | 34.60 | 33.87   | 34.68           |

Further in Table 5, the main technological and environmental factors are presented that affect the formation of a transport and logistics chain for the removal of waste from construction and demolition of buildings and structures.
Table 5. The main technological and environmental factors affecting the formation of a transport and logistics chain for the removal of waste from demolition of buildings and structures.

| No | Technological factors                                                                 | Environmental factors                                                                 |
|----|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 1  | Existing methods of demolition/dismantling of buildings and structures                   | Taking into account the negative impact of noise                                        |
|    |                                                                                        | Taking into account dust reduction                                                     |
| 2  | Methods for filling construction containers with demolition waste                       | Taking into account dust reduction                                                     |
| 3  | The choice of freight vehicles for the removal of containers, taking into account the urban road infrastructure | Taking into account the reduction of dust during transportation                          |
|    |                                                                                        | Taking into account air emissions from various types of fuel within the city            |
| 4  | Remoteness of the disposal/burial/recycling facility from the place of generation of demolition waste | Taking into account the reduction in the level of dust during transportation          |
|    |                                                                                        | Taking into account the reduction of traffic load within the city                     |

The construction waste and demolition products generated as a result of human construction activities are transported to a landfill or dumps located in the nearest distance in accordance with regulatory and legal documents implemented in the territory of the Russian Federation. This is often not the most strategic object in terms of strategic traffic management. Also, the products of construction activities are taken out to areas and objects in need of reclamation.

The presence of a large number of such facilities is explained by GOST R 57678–2017 clause 4.3 – if there are no enterprises in the region that can neutralize or recycle construction waste, then they must be taken to landfills and dumps with a disposal limit.

According to the “Program for the management of solid waste in St. Petersburg”, facilities for recycling, sorting, reloading, storing and burying solid waste are located on the territory of the city's districts. Data on them are given in tables 6 and 7.

Table 6. Data on the number of waste processing enterprises, landfills and waste sorting/waste transfer complexes in St. Petersburg.

| Category of facilities | Total amount | Of them, | Amount |
|------------------------|--------------|----------|--------|
| Waste recycling plants and landfills | 7 | New construction | 5 |
|                         |              | Reconstruction of object | 2 |
| Polygons                | 5 | Reclamation | 2 |
|                         |              | New construction | 2 |
|                         |              | In service | 1 |
| Waste sorting/waste transfer complexes | 17 | New construction | 15 |
|                         |              | Reconstruction of object | 2 |

According to the data in Table 7, it can be concluded that the majority of enterprises accredited to work with construction and demolition waste practically do not recycle this type of waste. From which it follows that burial or disposal cannot be carried out within the city or the places of generation of this type of waste and they must be transported to the place of disposal, burial over sufficiently long distances.
Table 7. Enterprises engaged in according to the Territorial scheme for waste management, processing, disposal, neutralization, placement of waste products of demolition (according to the program for waste management in St. Petersburg for 2020-2024).

| No | Name                                                                 | Processing | Disposal | Neutralization | Burial |
|----|----------------------------------------------------------------------|------------|----------|----------------|--------|
| 1  | SPb State Unitary Enterprise "Plant MPBO-2"                          | +          | -        | -              | -      |
| 2  | LLC "PROFSPETSTRANS"                                                | +          | +        | -              | +      |
| 3  | LLC "Lel-ECO"                                                       | +          | +        | -              | -      |
| 4  | LLC "Fuel Energy Company"                                            | +          | +        | -              | -      |
| 5  | JSC "Management Company for Waste Management in the Leningrad Region" | +          | +        | +              | +      |
| 6  | LLC "Novy Svet-ECO"                                                 | -          | -        | -              | +      |
| 7  | IP Karasev S.V.                                                     | +          | +        | -              | -      |
| 8  | LLC "Polygon MSW"                                                   | +          | +        | -              | -      |
| 9  | JSC "HELP-OIL"                                                      | -          | +        | -              | -      |
| 10 | LLC "AUTO-BERKUT"                                                   | -          | +        | -              | +      |
| 11 | LLC "Concept ECO"                                                   | +          | +        | -              | -      |
| 12 | LLC "SadService"                                                    | +          | -        | -              | -      |
| 13 | LLC "Dubrovskaya CHPP"                                              | -          | -        | -              | +      |
| 14 | CISC "Promotkhody"                                                  | -          | +        | -              | -      |
| 15 | LLC "Omega"                                                         | +          | +        | -              | -      |
| 16 | LLC "Regional Recycling Company"                                     | -          | +        | -              | -      |
| 17 | CISC "Vuoly-Eco"                                                    | -          | +        | -              | -      |
| 18 | LLC "UNEP"                                                          | -          | -        | +              | -      |
| 19 | LLC "Ivangorodsky Vodokanal"                                        | -          | -        | +              | -      |
| 20 | LLC Transneft-Port Primorsky                                        | -          | -        | +              | -      |
| 21 | LLC "PETROSERVICE"                                                  | -          | -        | -              | +      |
| 22 | JSC "Chisty gorod"                                                  | -          | -        | +              | -      |
| 23 | LLC "RASEM"                                                         | -          | -        | +              | -      |
| 24 | LLC "Eco PLANT"                                                     | +          | +        | -              | +      |

It can be seen from the tables that there are practically no objects for placement, disposal or recycling of waste, including construction and demolition waste, in the city. In connection with the above mentioned facts, it is necessary to take into account the conditions of transportation of construction and demolition waste.

4. Conclusions
1. The optimal choice of the method/way of dismantling/demolition of buildings and structures, as well as the method of filling containers with the resulting demolition waste, make it possible to form transport chains with minimal impact of negative factors affecting the environment during transportation to the place of disposal, recycling or burial of construction waste by vehicles.
2. Simulation modeling made it possible to form an optimal combination of important factors in the conditions of urban infrastructure, such as the volume and size of the container, the way/method of dismantling/demolition of building or structure, and the type of vehicle.
3. As a result of the research, the factors influencing the formation of the transport chain were identified, which reduce the negative impact of some harmful factors on the environment during the transportation of construction waste.

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