Logistic Problem Connected with Removing Asbestos as Dangerous Waste from Terrains of Country Communes

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Abstract. Asbestos is a common term referring to certain mineral groups having the form of fibers with a length to fiber diameter of at least 100: 1. The specific properties of asbestos - flammability, mechanical strength and thermal and flexibility - meant that asbestos has been widely used in various types of industrial technologies. It is classified as hazardous waste and therefore requires special methods for collection, export and disposal. The article proposes a model of logistics exports of asbestos from selected villages, in order to guarantee the shortest route, while maintaining the ecological safety and the rules of transportation of hazardous waste.

1. Introduction
Management of hazardous waste is part of a complex system, whose negligence may cause a serious threat to all components of the environment (soil, water, air). Due to their properties and possibilities of interaction, a very important element is the proper management of the collection, storage, transport, or the recovery, recycling and final safe disposal [1, 2]. According to the law on waste, hazardous waste means waste, which displays one or more of the hazardous properties [3]. Properties that make the waste hazardous waste set out in Annex 3 to the above-mentioned Act. In addition, Annex 4 of the Act lists the ingredients that may cause that the waste is hazardous waste. Among them is mentioned asbestos (dust and fibers). According to the Waste Catalogue [4], are classified 9 types of waste, in 5 groups of waste (depending on the source formation), the largest group of asbestos waste constitutes waste insulation and asbestos-containing construction of a group of 17 waste from construction and demolition of buildings and road infrastructure. Due to the harmfulness of asbestos is a group of waste, which are treated in a special way and created for them a separate management system. This article presents the opportunity to optimize the transport of asbestos waste, which takes into account not only its harmfulness, but also the technical aspects of the dismantling, removal and disposal of such waste.

2. Material and methods
2.1 The properties of asbestos
Asbestos is a common term referring to certain groups having the form of mineral fibers with a length to fibre diameter of at least 100: 1. The name asbestos does not specify a specific mineral, but the total of fibre-forming silicate minerals. These include proper asbestos: serpentine asbestos and amphibole. It is understood that variations asbestos are fibrous minerals occurring in nature in the form of fibre bundles, which are characterized by high tensile strength, flexibility, and resistance to chemical and physical factors. Asbestos is a generic name covering fibrous minerals from the group of serpentine
and amphibole. This name derives from the Greek word “asbestos”, which meant unfading or indestructible. The ancient Greeks used it, because the product wicks in lamps groves. Commonly used on a large scale was only after World War II. It was used mainly due to the properties of non-flammable and low price. Thanks to a long-known and valued resistance to high temperatures, the three minerals Asbestos became popular and widely used in the global economy. These are: the most common chrysotile (white asbestos), to a lesser extent, used crocidolite (blue asbestos), and even more rarely used amosite (brown asbestos), [5-8].

The specific properties of asbestos - flammability, mechanical strength and thermal resistance and flexibility - caused that asbestos is widely used in various types of industrial technologies. Mechanical strength of asbestos fibers after heating to 350°C drops to only 20% (due to the removal of parts of water). However, after the adoption of the water from the humid it returns to its previous state. Only the temperature over 700 °C results in complete evaporation of water and the irreversible destruction of the material (the fibers lose their elasticity and begin to crumble) [6, 9].

The largest amount of raw material (approximately 85% of total consumption) was used in building materials mainly for the manufacture of roofing and cladding asbestos - cement panels. Asbestos was used on a large scale to the mid-eighties, until proved harmful effects of this material for human health.

Studies have shown the carcinogenic effect of asbestos fibers that get into the body from inhaled air. These are fibre thickness of less than 3 mm, a length greater than 45 microns (ratio - length: diameter> 3: 1). Inhalation asbestos can cause serious illnesses, including asbestosis (asbestosis), pleural changes and lung carcinoma. These diseases have a long incubation period and can reveal even after 30 years since the absorption fibers.

Since 1998 is strictly prohibited of production and use of asbestos. And according to the EU directive [10-11] and Polish document entitled Country Asbestos Treatment Program for the year’s 2009-2032 year asbestos must be removed and disposed of in a safe manner. Poland is the first country in the European Union, which took up the challenge to withdraw from the use of products containing asbestos.

2.2 Asbestos waste methods of collection

Due to the properties and risk posed by the asbestos, are extremely important principles of its collection. The basic rule for this type of activity is the greatest protection against the possibility of the waste emissions of asbestos fibers into the atmosphere. This is achieved through the use of appropriate technical and proper organization [12]. The most important is to maintain the disposal of waste in the moist state and to avoid damage to removed object, and especially the use of mechanical machining methods and the use of suitable sealed packaging. It is also important protection of people collecting and dealing with the removal of asbestos waste [13-14].

Waste having a bulk density above 1000 kg / m3 (containing less than 20% asbestos) should be hermetically wrapped with a polyethylene film and permanently bonded on pallets. And waste of the bulk density of less than 1000 kg / m3 (containing more than 20% asbestos) and asbestos dust should be placed in bags of polyethylene film, after sealing the bags by heat sealing or sticking the adhesive tape, placed in the packaging container type "Big -Bag "of plastics. Waste with edges sharp (contaminated with asbestos), egg. metals parts, pieces of construction should be packed in boxes and wrapped with polyethylene film or placed in bags with foil. All asbestos waste packaging should be marked an international warning sign. [3].

2.3 Asbestos waste disposal technologies and methods

The basic method of disposal of asbestos in our country is their depositing in landfills. Deposit principles suggest regulation of the Minister of Environment of 30 April 2013 on the landfill of waste [15]. According to § 19 of the regulation in hazardous waste landfills or on a separate part in landfills for non-hazardous and inert solely for the storage of hazardous waste may be disposed of asbestos waste from construction, renovation and demolition of buildings and road infrastructure, specified in the waste catalogue, marked with the codes 17 06 01 * insulation materials containing asbestos or 17 06 05 * construction materials containing asbestos. This waste cannot contain dangerous substances other than asbestos in a bonded form, together with the fibers bound by a binding agent, in the form of unconverted. These wastes are stored in the package in which they were delivered to the landfill. Each
time after placing the waste in the landfill waste their surface protects itself against dust emission by covering synthetic insulation or layer of soil. Landfill or accommodation unit is not carried out work that could lead to a release of fibers. Storage of asbestos waste must be completed 2 m below surrounding ground level; then the landfill is filled with soil to ground level. After filling the landfill layer of soil, they cannot be built buildings, carried out excavations, over ground and underground or cannot be carried out works affecting the structure of this landfill [15].

A popular form of disposal of dusty waste with a high content of asbestos is their dumping of cement in the concrete mix before depositing. Formed in this way concrete - asbestos blocks have limited clean ability, but still are treated as hazardous waste.

Another method of disposing asbestos is a thermal method, which uses ATON 200 unit. In this method, the waste containing asbestos, after initial crushing in crusher are mixed with adjuvant and introduced into the reactor chamber microwave. As a result of heating the mixture to a temperature of about 1100 ° C the asbestos fibers are broken. Asbestos loses its fibre structure and the resulting material loses its harmful properties. A characteristic feature of this method is heating the asbestos waste using concentrated microwave field which penetrates deeply into the material heats at the same time its entire volume [9, 16-17].

2.4 State of asbestos waste management in Poland

Methods of disposal of asbestos in Poland are regulated by "Country Asbestos Treatment Program for the years 2009-2032". The document maintains the objectives adopted by the Council of Ministers on 14 May 2002 "Program for disposal of asbestos and products containing asbestos used on Polish territory" and indicates the need for: removal and disposal of asbestos-containing products; minimize the negative health effects caused by the presence of asbestos in the country; elimination of harmful effects of asbestos on the environment.

This document diagnoses the current state of asbestos waste management in our country, defines the objectives and tasks and possibilities of financing of the program and describes the potential benefits of its operation on the social, environmental and economic levels. It is estimated that the country is still in use is approx. 14.5 million tons of products containing asbestos (2003-2008 removed approx. 1 million tons).

Data on the current status of asbestos waste management are catalogued and described in Asbestos Database. Specifies the balance of asbestos waste inventoried, disposed of and remained for disposal in the country and in different provinces.

The graph below shows the mass of asbestos in the form of flat panels, wavy panels and other products containing asbestos, used in construction (figure 1).

The figure above shows (Fig. 1), that the biggest group of asbestos waste, are the remaining waste for disposal. In addition, an overwhelming group of waste is asbestos cement wavy panels used in construction. Disposal of waste in all provinces is still a significant problem.

2.5 Export logistics asbestos waste from the community – assumptions for calculation

For the purposes of calculation assumed:
1. Municipality X has a rural character of single-family and dispersed structure of buildings. The village population is about 14 thousand residents.
2. In the municipality carried out an inventory of asbestos waste codes 17 06 01 * Insulation materials containing asbestos or 17 06 05 * Construction materials containing asbestos [4, 19]
3. There are five landfills in which wastes can be deposited asbestos (summarized in Table 1).
4. Distances from the community to individual landfills are summarized in Table 1. The distance was measured from the center of village to the entrance gate to the landfill. It was taken into account the fact that it is not always a direct connection between the municipality and the landfill.

Calculations and statements refer to different places and landfills.
Figure 1. The mass of products containing asbestos: inventoried, disposed of and remained for disposal [18]

Table 1. Landfills data summary, which can potentially take asbestos waste, included in the calculation

| Landfill No | Capacity      | Remaining capacity | Distance |
|------------|---------------|--------------------|----------|
| 1          | 8 870 m³      | 6 209 m³           | ok. 20 km|
| 2          | 468 952 m³    | 414 062 m³         | ok. 80 km|
| 3          | 17 452 m³     | 12 957 m³          | ok. 40 km|
| 4          | 5 903 m³      | 590 m³             | ok. 100 km|
| 5          | 4 200 m³      | 3 837 m³           | ok. 135 km|

Table 2. Summary of localities belonging to the municipality and the amount of asbestos in different localities

| Village | The 1st degree of urgency | The 2nd degree of urgency | The 3rd degree of urgency | Removed asbestos |
|---------|---------------------------|---------------------------|---------------------------|------------------|
| symbol | [kg]                       |                           |                           |                  |
| A      | 0                         | 16 775                    | 113 949                   | 16 775           |
| B      | 0                         | 2 607                     | 51 161                    | 2 607            |
| C      | 0                         | 17 413                    | 135 014                   | 17 413           |
| D      | 0                         | 7 150                     | 46 145                    | 7 150            |
| E      | 0                         | 11 121                    | 224 950                   | 11 121           |
| F      | 0                         | 16 412                    | 545 429                   | 16 412           |
| G      | 0                         | 10 461                    | 74 030                    | 10 461           |
| H      | 0                         | 28 919                    | 280 654                   | 28 919           |
| I      | 0                         | 16 280                    | 117 106                   | 16 280           |
| J      | 0                         | 5 665                     | 52 800                    | 5 665            |
| K      | 0                         | 18 359                    | 205 568                   | 18 359           |
| L      | 0                         | 3 410                     | 25 212                    | 3 410            |
| M      | 0                         | 11 550                    | 69 707                    | 11 550           |

0 166 122 1 941 725 166 122
The inventory data is made considering the degree of urgency of the removal of asbestos waste, according to the assumptions: the 1st degree of urgency – required urgent removal (replacement for non-asbestos product) or protection, the 2nd degree of urgency – required a reassessment within one year, the 3rd degree of urgency – required a reassessment within five years (inventories are carried out once every 5 years). Inventory data placed in Table 2.

The analysis of the condition of asbestos in any case did not require urgent removal (as the result of the points), but the most urgent to remove considered are already removed asbestos roof panels (so their amount was specified in a separate column) [20-22].

3. Results and discussion

3.1 Problem of optimization of asbestos wastes transport to neutralize spots

The methods minimizing the costs or ride time are used in management of productive or logistic enterprises. In the literature one may also encounter descriptions of telematics and computer systems being used to optimizing routes of transport [23].

General examples of possibility of SIP software utilization to spatial analyses being executed on the level of typical commune, including the choice of optimal rout of ride between localities considering criterion of costs, was contained in the articles [24]. Executed analyses can be useful in the process of taking decision, among others in range of investments’ influence on environment or the location of investment. They enable to quickly receive different scripts connected with taking decision, especially in case of recurrent problems.

Apart from questions which concern the optimization of transport routes of asbestos, the compliance with legal rules related to transport is important, too. Products, which contain asbestos in some situation, come under ADR rules (fr. L’ Accord européen relatif au transport international des marchandises Dangereuses par Route), e.g. when the liberation of the asbestos fibres during transport is possible. Problems relating to transport and storing asbestos is comprised, among others, in the article [13, 17, 20 - 22].

Below there is presented the manner of building mathematical model which allows to determine the optimal route of ride of vehicles that take asbestos from places where it is (private properties), and take it to especially prepared storages of asbestos wastes. The model is based on data on the actual area of occurrence of asbestos data as well as existing storages. Optimization criteria, which should be taken into account in the construction of this type of model, are: minimizing the route of vehicles (smaller probability of terrain contamination, smaller pollution, lower fuel costs), maximization of utilization of vehicles loading space and working time of drivers resulting from corresponding rules.

3.2 Construction and analysis of the mathematical model

Analysing the conditions of introducing of activities connected with transport optimization, one can use mathematical models [25-28]:

1. Those conditions should take into account:
   - degree of utilization diligence, where \( u = I, II, ... U \)
   - quantity of asbestos wastes with \( u \) – degree of utilization diligence \( [t] \) in analysed example \( u = I, II, III \):
     - \( SP_I \) – quantity of asbestos wastes with I degree of utilization diligence \( [t] \)
     - \( SP_{II} \) – quantity of asbestos wastes with II degree of utilization diligence \( [t] \)
     - \( SP_{III} \) – quantity of asbestos wastes with III degree of utilization diligence \( [t] \)
     - \( SP_{u=m} \) – quantity of asbestos wastes with \( u \) – degree of utilization diligence from locality \( m \), in analysed example
     - \( SP_{I,1}, SP_{I,2}, ... , SP_{I,m} \) – quantity of asbestos wastes with I degree of utilization diligence from locality \( m = 1, 2, ... M \)
     - \( SP_{II,1}, SP_{II,2}, ... , SP_{II,m} \) – quantity of asbestos wastes with II degree of utilization diligence from locality \( m = 1, 2, ... M \)
     - \( SP_{III,1}, SP_{III,2}, ... , SP_{III,m} \) – quantity of asbestos wastes with III degree of utilization diligence from locality \( m = 1, 2, ... M \)
   - \( SK_1, SK_2, ... , SK_k \) – capacity of storage, where \( k = 1, 2, ... K \), in analysed example:
     - \( SK_i \) – free capacity of storage \( i \)
SK\(_2\) - free capacity of storage 2
SK\(_3\) - free capacity of storage 3
SK\(_4\) - free capacity of storage 4
SK\(_5\) - free capacity of storage 5

Restrictive conditions:
It has been assumed, that:

\[
\sum_{u=1}^{U} SP_u \subseteq \sum_{k=1}^{K} SK_k
\]

which means, that we want to place all the wastes on the nearest storage.

Necessary condition:

\[
\sum_{u=1}^{U} SP_u \leq \sum_{k=1}^{K} SK_k
\]

where:

\( k = 1, 2, \ldots K; \quad u = I, II, \ldots U; \quad k, u \in C; \quad k = 5; \quad U = III, \)

General limitations, relating to receiving all wastes from a commune, about different degree of utilization diligence to one storage have form:

\[
\sum_{k=1}^{K} \sum_{u=1}^{U} SK_u \geq \sum_{u=1}^{U} \sum_{m=1}^{M} SP_{u-m}
\]

where:

\( m = 1, 2, \ldots M \) – numbers of individual localities from which asbestos is taken away

Limitations restricting the area of searches are:
1. Possible criteria of choice, e.g.: storage’s capacity, distance from locality, journey time, journey costs, emission of fumes.
2. Choice of criteria:
   a) storage capacity— one should check possibilities of receiving asbestos from whole commune to individual storage:
      \( SK_1 = 8870 \text{ m}^3 \) – free capacity of storage 1
      \( SK_2 = 67766 \text{ m}^3 \) – free capacity of storage 2
      \( SK_3 = 15000 \text{ m}^3 \) – free capacity of storage 3
      \( SK_4 = 200 \text{ m}^3 \) – free capacity of storage 4
      \( SK_5 = 35643 \text{ m}^3 \) – free capacity of storage 5

   Assuming that 1 m\(^2\) = 11 kg of asbestos:
   \[
   \sum_{m=1}^{M} SP_{I=m} = 0 \quad (4)
   \]
   \[
   \sum_{m=1}^{M} SP_{II-m} = 166122kg \approx 15 \text{ km}^3 \quad (5)
   \]
   \[
   \sum_{m=1}^{M} SP_{III-m} = 1941725kg \approx 1765 \text{ km}^3 \quad (6)
   \]
   asbestos with II degree of diligence can be received to every storage, and asbestos with III degree of diligence can not be received to storage 4.
   b) assuming the linear dependence between distance, journey time, journey costs and emission of fumes, distance was taken as the criterion,
   c) we choose a storage laid in the smallest distance from a commune:
   
   \[
   FC (l_{k,m}, l_{i,m}, \ldots l_{i,m}) \rightarrow min \quad \text{for} \quad k = 1, 2, \ldots K, \quad m = 1, 2, \ldots M.
   \]
   where: \( FC \) – function of aim, \( l_{k,m} \) – distance of storage \( k \) from locality \( m \) in analysed example:
   From assumptions of the task there has been chosen locality \( I \) \((m = I)\) from which all vehicles with asbestos go to locality where the storage is.
On the ground of the distance table, the arrangement of distance sequence was made: 

\[ l_{1,1} < l_{3,1} < l_{2,1} < l_{4,1} < l_{5,1} \rightarrow \text{storage 1 was chosen, because } l_{1,1} - \text{distance of storage 1 from locality 1 is the smallest one.}\]

The criteria of optimization are:

1. route of ride minimizing the distance between localities and storage,
2. utilization of the loading capacity of cars,
3. drivers' work time.

Assuming as the criterion of optimization the route of ride minimizing the distance between localities and storage, the composition of distances presented in tab. 1 have been received.

### Table 3. Table of distances and possible connections between localities

| Locality | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|----------|---|---|---|---|---|---|---|---|---|----|----|----|----|
| 1        |   | 1,5|   |   |   |   |   |   |   | 2,2|    |    |    |
| 2        | 1,5|   | 2,2|   |   |   |   |   |   |    | 2,4|    |    |
| 3        |   | 2,2|   | 2,5|   |   |   |   |   |    |    |    |    |
| 4        |   |   | 2,5|   | 3,7|   |   |   |   |    |    |    | 4,8|
| 5        |   |   |   | 3,7|   | 5,3|   |   |   |    |    |    |    |
| 6        |   |   |   |   | 5,3|   | 2,3|   |   |    |    |    |    |
| 7        |   |   |   |   |   | 2,3|   | 4,7|   |    |    |    |    |
| 8        |   |   |   |   |   |   | 4,7| 4,8|   | 4,4|    |    |    |
| 9        |   |   |   |   |   |   |   | 4,4| 4,4|    |    |    |    |
| 10       |   |   |   |   |   |   |   |   | 4,4| 3,2|    | 2,3|    |
| 11       |   |   |   |   |   |   |   |   |   | 2,3|    |    |    |
| 12       | 2,2|   |   |   |   |   |   |   |   |    |    | 4,4|    |
| 13       | 2,2| 2,4|   |   |   |   | 4,8| 3,8|   |    |    |    |    |

Restrictions relating to the order of localities on the route has been made for following junctions (table 4). Border conditions have the following form:

\[ x_{ij} = 0 \text{ or } 1 \]

\[ 0 = < m_i = < 11 \]  

### Table 4. Table of junctions A.

| Junction m₂ : | Junction m₆ : | Junction m₁₀ : |
|---------------|---------------|---------------|
| \( m_2 - m_3 + 13 \times x_{3,3} \leq 12 \) | \( m_6 - m_5 + 13 \times x_{6,6} \leq 12 \) | \( m_{10} - m_{11} + 13 \times x_{10,11} \leq 12 \) |

| Junction m₃ : | Junction m₇ : | Junction m₁₁ : |
|---------------|---------------|---------------|
| \( m_3 - m_4 + 13 \times x_{3,4} \leq 12 \) | \( m_7 - m_6 + 13 \times x_{7,6} \leq 12 \) | \( m_{11} - m_{10} + 13 \times x_{11,10} \leq 12 \) |

| Junction m₄ : | Junction m₈ : | Junction m₁₂ : |
|---------------|---------------|---------------|
| \( m_4 - m_3 + 13 \times x_{4,3} \leq 12 \) | \( m_8 - m_7 + 13 \times x_{8,7} \leq 12 \) | \( m_{12} - m_{11} + 13 \times x_{12,11} \leq 12 \) |

| Junction m₅ : | Junction m₉ : | Junction m₁₃ : |
|---------------|---------------|---------------|
| \( m_5 - m_{13} + 13 \times x_{5,13} \leq 12 \) | \( m_9 - m_8 + 13 \times x_{9,8} \leq 12 \) | \( m_{13} - m_2 + 13 \times x_{13,2} \leq 12 \) |

| Junction m₆ : | Junction m₁₀ : | Junction m₁₁ : |
|---------------|---------------|---------------|
| \( m_6 - m_5 + 13 \times x_{6,5} \leq 12 \) | \( m_{10} - m_9 + 13 \times x_{10,9} \leq 12 \) | \( m_{11} - m_{12} + 13 \times x_{11,12} \leq 12 \) |

| Junction m₇ : | Junction m₉ : | Junction m₁₂ : |
|---------------|---------------|---------------|
| \( m_7 - m_6 + 13 \times x_{7,6} \leq 12 \) | \( m_9 - m_8 + 13 \times x_{9,8} \leq 12 \) | \( m_{12} - m_{11} + 13 \times x_{12,11} \leq 12 \) |

| Junction m₈ : | Junction m₁₀ : | Junction m₁₁ : |
|---------------|---------------|---------------|
| \( m_8 - m_7 + 13 \times x_{8,7} \leq 12 \) | \( m_{10} - m_9 + 13 \times x_{10,9} \leq 12 \) | \( m_{11} - m_{12} + 13 \times x_{11,12} \leq 12 \) |

| Junction m₉ : | Junction m₁₀ : | Junction m₁₁ : |
|---------------|---------------|---------------|
| \( m_9 - m_8 + 13 \times x_{9,8} \leq 12 \) | \( m_{10} - m_9 + 13 \times x_{10,9} \leq 12 \) | \( m_{11} - m_{12} + 13 \times x_{11,12} \leq 12 \) |

| Junction m₁₀ : | Junction m₁₁ : |
|---------------|---------------|
| \( m_{10} - m_9 + 13 \times x_{10,9} \leq 12 \) | \( m_{11} - m_{12} + 13 \times x_{11,12} \leq 12 \) |

| Junction m₁₁ : |
|---------------|
| \( m_{11} - m_{12} + 13 \times x_{11,12} \leq 12 \) |

| Junction m₁₂ : |
|---------------|
| \( m_{12} - m_{11} + 13 \times x_{12,11} \leq 12 \) |

| Junction m₁₃ : |
|---------------|
| \( m_{13} - m_{12} + 13 \times x_{13,12} \leq 12 \) |
Conditions referring to single-time entrance and departure from a city for individual junctions (table 5).

| Junction m₁: | Junction m₆: | Junction m₁₁: |
|--------------|--------------|--------------|
| $x_{1,2} + x_{1,12} + x_{1,13} = 1$ | $x_{6,5} + x_{6,7} = 1$ | $x_{11,9} + x_{11,10} + x_{11,12} = 1$ |
| $x_{2,1} + x_{12,1} + x_{13,1} = 1$ | $x_{5,6} + x_{7,8} = 1$ | $x_{9,11} + x_{10,11} + x_{12,11} = 1$ |

| Junction m₇: | Junction m₈: | Junction m₁₂: |
|--------------|--------------|--------------|
| $x_{2,1} + x_{2,3} + x_{2,13} = 1$ | $x_{7,6} + x_{7,8} = 1$ | $x_{12,1} + x_{12,11} = 1$ |
| $x_{1,2} + x_{1,3} + x_{1,12} = 1$ | $x_{6,7} + x_{8,9} = 1$ | $x_{1,12} + x_{11,12} = 1$ |

| Junction m₉: | Junction m₁₀: |
|--------------|--------------|
| $x_{3,2} + x_{3,4} = 1$ | $x_{8,7} + x_{8,9} + x_{8,11} = 1$ |
| $x_{3,3} + x_{4,3} = 1$ | $x_{7,8} + x_{9,8} + x_{12,8} = 1$ |
| $x_{3,3} + x_{4,4} = 1$ | $x_{7,8} + x_{9,8} + x_{12,8} = 1$ |
| $x_{3,4} + x_{4,4} + x_{4,13} = 1$ | $x_{7,8} + x_{9,10} + x_{9,11} = 1$ |
| $x_{3,4} + x_{5,4} + x_{13,4} = 1$ | $x_{8,9} + x_{10,9} + x_{11,9} = 1$ |

In full coherent graph (such which every 2 apexes can be joined with road) with $n$ apexes there is $(n-1)!$ cycles. For symmetrical graph the quantity of cycles figures out $\frac{(n-1)!}{2}$.

For $n = 13$:

$\frac{(n-1)!}{2} = \frac{(13-1)!}{2} = \frac{12!}{2} = 479001600$  \(10\)

Data for the task are considerably simpler, and the number of possible connections between localities is limited (table 1). In the given arrangement of localities, given restrictions and wastes quantity smaller than capacity of car (condition for example not fulfilled), the order of visiting the cities assuring the smallest distance and minimum costs is following:

$m_1 - m_{12} - m_{11} - m_{10} - m_9 - m_8 - m_7 - m_6 - m_5 - m_4 - m_3 - m_2 - m_{13} - m_1$

The total length of FC rides figures out: $FC = 42.2$ km.

The second of criteria of optimization concerned the possibility of utilization of cars’ loading capacity. To the analysis there have been accepted vehicles about 10 [t] of load capacity 10 [t]. To solve the task, it should be assumed, that:

$Q_t > SP_{u-m}$  \(11\)

where: $Q_t$ - load capacity of vehicle [t], $t$ - quantity of tons of the load which can be conveyed.

From the list of asbestos quantity in individual localities results, that for the II degree of utilization diligence there is following dependencies described by inequalities:

$Q_{10} < SP_{10,11}$  \(12\),

$Q_{10} < SP_{10,13}$  \(13\),

$Q_{10} < SP_{10,7}$  \(14\),

$Q_{10} < SP_{10,8}$  \(15\),

$Q_{10} < SP_{10,3}$  \(16\),

$Q_{10} < SP_{10,5}$  \(17\),

$Q_{10} < SP_{10,4}$  \(18\),

$Q_{10} < SP_{9,1}$  \(19\),

$Q_{10} < SP_{9,6}$  \(20\)

and for the III degree of utilization diligence there is following dependence:

$\bigwedge SP_{u-m} > Q_{10}$  \(21\)

Loading capacity of vehicles is smaller than quantity of the load to be convey from a given locality. In this connexion there are possibilities of:

1. transporting loads joining them with loads from other localities so to use the whole capacity of vehicle – separate optimization question come into being,
2. transporting loads which surpass the capacity of vehicle as separate drives, without filling-up vehicles in next drives,
3. using vehicles which have bigger load capacity, e.g. $Q_t = 20$ [t], which causes that:
   a) another optimization question come into being that is related to: issue referring to diverse petrol consuming by vehicles with larger tonnage, greater emission of fumes, limitations of ride on roads about smaller carries capacity,
   b) in case of $Q_t = 20$ [t] all loads from given locality have enough room in vehicle, but in every of cases the maximum load capacity will not be used that is we will not get the optimum solution.
The last of analysed criteria is drivers’ work time. About drivers’ work time tells: decree of [29] of European Parliament and Council, and law about time of drivers’ work [30].

Those regulations are quite complicated, considering the safety of drive they impose necessary pauses during driving, daytime periods of rest, rules of breaking daytime rest, daytime periods of rest in case of driving by two drivers, time of driving and resting in next weeks, balanced system of work etc. One should also take into account: time of time of loading and discharge, time for preparing documentation connected with transportation, time of disguise in protective dress, time for additional activities etc.

For described case the average quantity of asbestos to be taken from every locality is about 12.8 tons. Assuming that loading is hand operated and two drivers simultaneously loads 6 plates about dimensions 1 x 1 m, which gives 66 kg, the average quantity of loading in given locality figure out 194.

With assumption of loading time being 2 [min.] we receive:

$$194 \times 2 \text{ min.} = 388 \text{ min.} = 6.47 \text{ hours.}$$

In balanced system of work driver can work up to 12 hours/day, and in the scale of week 48 hours with hours of extra work.

So one can:
1. perform one drive to one locality in given day, which with comparatively small distances between localities and large differentiation in quantity of asbestos in individual localities may lead to not fully used time of workers’ work,
2. try to match localities but there is a problem how to assign the work in optimum and compliant with regulations way.

Making the time of loading real, needed among others to completing of plates or their segregation and completing (e.g. in case of damaged plates), to 4 [min.] we receive:

$$194 \times 4 \text{ [min.]} = 776 \text{ [min.]} = 12.93 \text{ [h]},$$

so there is exceeding of admissible time. To above mention times one can add times connected with manoeuvre drives and filling records.

4. Conclusions
The analysis presented in this article, permits on executing the model optimizing road transportation of dangerous wastes, e.g. of asbestos elements. Including limitations imposed on decision variables of optimization task may contribute to finding the most profitable route of transport, taking into account following parameters: logistic, ecological, economic and social. Large computational complexity of that investigative problem requires using complex computational algorithm, detailed analysis of variables dependent and independent, as well as relationship between individual component processes of transportation of dangerous wastes. Including ADR rules regulating technical as well as legal conditions connected with transportation is essential, too.

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