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LOGISTICS-BASED DESIGN OF COLLECTION SYSTEM FOR ASBESTOS-CONTAINING ROOF STRUCTURES

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Abstract: *Asbestos-containing roofing materials are an increasing hazard, which justifies their replacement by environmentally friendly roofing materials. Replacements can be carried out on an individual initiative basis, but a coordinated, systemic replacement will have a more significant impact. In order for such systemic asbestos removal to be successful from economics and logistics point of view, it is necessary to plan the associated logistics processes, as asbestos removal generates a significant transportation demand due to the large amount of waste generated. In the framework of this paper, the author presents an algorithm to plan the logistic process of centralized asbestos removal. A simple calculation method is presented to determine the cost of collection.*

Keywords: *asbestos-containing roofing materials, replacement, logistics design, cost function*

1. INTRODUCTION

The ecological and occupational evaluation of chrysotile-asbestos fibers emitted during construction and exploitation by roof materials made of asbestos cement shows the potential high risk factors [1, 2]. The first phase of the design of asbestos-containing roof collection is the approximation and forecasting of the amount of asbestos-containing roof materials and roof structures, therefore the detection of asbestos-containing roof structures is an important part for the preparation of projects focusing on the change of asbestos-containing roof structures [3-7].

The operations related to asbestos-containing roof structures have a wide range of risks, therefore it is always important to identify the potential risks and find the potential solutions to minimize the negative impacts [8]. These risks are summarized by Kfoury et al in a case study in North Lebanon [9]. These risks are generally leading of development of new asbestos free roof sheets [10]. One of the most important and most dangerous negative impact of asbestos-containing roof structures is related to the particle emission [11] for example the releasability of asbestos fibers from weathered roof structures [12, 13], corrosion [14, 15]. Not only particle emission but also physical properties of asbestos-cement roof sheeting after long-term exposure must be taken into consideration [16].

The asbestos-containing roof sheets are not only dangerous, but their thermal performance is also significantly lower than other green solutions [17].

The change of asbestos-containing roof structure especially complicated problems in the case of heritage building, where the roof structure belongs to the heritage, while roof leaking problems have also negative impact on the structure of the whole building [18].

Industry 4.0 technologies and emerging technologies are also used for the design and control of the asbestos-containing roof related problems (identification, clustering, machine vision) [19].

Researchers stated, that the efficiency and performance of solar panels are significantly influenced by the roof materials, as Hamzah et al. mention their research work [20].

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Occupational health is focusing on the asbestos-containing roof structure problems. The main research fields are the followings:

- nitrifying bacteria on the asbestos-cement roofs of stable buildings [21],
- safety during work on asbestos-cement corrugated roofs [22],
- precautionary measures for asbestos-cement corrugated roofs [23],
- asbestos exposure level and the carcinogenic risk due to corrugated asbestos-cement slate roofs in Korea [24],
- mobilization of asbestos fibers by weathering of a corrugated asbestos cement roof [25],
- relationships of lower lung fibrosis, pleural disease, and lung mass with occupational, household, neighbourhood, and slate roof-dense area residential asbestos exposure [26],
- occupational asbestos exposure in the removal and protective treatment of eternit roof coverings [27],
- occupational health and hygiene following a fire in a warehouse with an asbestos cement roof [28, 29].

These research directions show the importance of the optimal design and control of asbestos-containing roof structure change processes.

The design and operation of asbestos-containing roof structure changing process is a special technological and logistics problem, because the operations cannot be integrated into conventional collection and recycling processes. Containers must be assigned directly to the collection process of asbestos-containing roof structures. As AfzetBak defines [30], in a construction and demolition waste container the following materials are allowed: aerated concrete, all types of wood, cardboard, cast, clean rubble, foil, gibo, insulation, metal, paper, plastic, plastics, stones. Important, that the same source defines, that the following materials are not allowed: mattresses, asbestos, asbestos-like, car tires, chemical waste, fridge / freezer, hazardous waste and roof waste. Section 2 describes the algorithm of the planning of the collection process of used asbestos-containing roof sheets and roof structures. Section 3 presents a potential approach for the financial evaluation of collection processes focusing on the transportation of collected asbestos-containing roof structures (sheets). Conclusions and future research directions are discussed in Section 4.

2. ALGORITHM

In the operation of a collection system for asbestos-containing roof structures, a number of design tasks need to be addressed to ensure optimal efficiency:

- determining the quantities to be processed,
- selection of the container,
- determining the amount of containers required,
- selection of a disposal plant for roof structure containing the demolished asbestos collected in the container (co-location of the plant and the recycler),
- selection of transport vehicles for the collection of the containers,
- determination of the number of routes required per municipality, per disposal plant and for the whole system,
- determination of mileage per municipality, per disposal plant and for the whole system,

- determination of the cost of the collection system.

Below, we look at the criteria that should be used to make decisions at each stage of the system design:

1. Determining the quantity to be processed:
   - National extension of the quantities of waste to be collected, as known from the data collection, to all municipalities in the country,
   - The generalisation from the data can be done by averaging or in proportion to the population of the municipalities.
2. Selection of a container for the collection of roofing materials containing demolished asbestos:
   - for the removal of the roofing material generated, it is advisable to choose a container of a size that can be transported economically,
   - a container other than the optimum size may be justified in cases where an optimum size container is not available.
3. Determine the quantity of containers required:
   - Whereas the investigation of different system variants has shown that container collection is the most appropriate, however, among the known roller (see Figure 1) and chain containers (see Figure 2), chain containers are basically the most appropriate for the collection of construction waste, since roller containers cannot be used to load construction waste with sufficient volume efficiency due to their high weight,
   - to determine the required volume of container, the first step is to determine the density of the asbestos-containing roofing materials to be collected, on the basis of which the required container volume or mass can be calculated,
   - from the total container volume thus calculated (which is in fact the total expected volume of asbestos-containing roofing material converted into containers), the average container volume required to safely operate the collection system can be determined, taking into account the duration of the whole process,
4. Selection of a processor for the containerised collected demolished asbestos roofing material (co-location of plant and disposal):
   - it is preferable to choose the disposal plant close to the settlement, but this should not be a static decision, but should allow for dynamic allocation depending on the speed of removal of the demolished asbestos roofing material, in which case the involvement of a more distant processing site may lead to additional costs,
   - collection is not only an assignment task, but may also require scheduling tasks, depending on the storage and processing capacity of the disposal plant, and ensuring that the amount of roofing material delivered to the processor does not exceed the available storage capacity,
   - the scheduling may be constrained by the continuous operation of the processing technology.
5. Selection of transport vehicles for the collection of the stacked containers,
   - if several types of transport vehicles are available, it is advisable to choose the most economical one,
   - as there is only one type of vehicle available for chain containers, only the possibility of using a trailer vehicle is considered as a decision variable.

6. Determine the number of runs required per municipality, per processor and for the whole system,
   - as the collection process is essentially containerised, the use of shuttle services should be the preferred option, as the implementation of collection services would require unrealistic roof opening and timetabling tasks.
7. Determination of mileage per municipality, per processor and for the whole system,
   - the determination of the mileage can be clearly done on the basis of the parameters defined above, its distribution over time depending on the practical implementation of the system.
8. Determination of the cost of the collection system,
   - can be determined on the basis of the type and required number of containers, the number of collection vehicles and their mileage.

Figure 1. Roller container [31]

Figure 2. Chain container [32]

3. FINANCIAL EVALUATION MODEL FOR THE COLLECTION OF ASBESTOS CONTAINING ROOF STRUCTURES

For the calculation of the cost of the collection system, a cost model is formulated that is suitable for determining the transportation cost for the shuttle solution.

To determine the cost of the collection system, the first step is to calculate the volume of the roofing material containing demolished asbestos generated, as this is the only way to take into account the volume and weight limits for the number and size of containers required. The volume of demolished asbestos-containing roofing material generated can be determined by settlements as follows:

$$V_t = \frac{q_t}{\rho}$$

Based on this volume, it is possible to determine the quantities of each type of container available that are required per municipality for a homogeneous container stock with different densities of demolished roofs. If the density of the demolished roof structure is less than the quotient of the container's load capacity and its useful volume, the volume of demolished roof generated can be used to calculate the quantity of demolished roof in terms of container units:

$$\rho \leq \frac{K_k}{V_k} \rightarrow N_t = \frac{V_t}{V_k}$$

If the density of the dismantled roof structure is greater than the quotient of the container's load capacity and its useful volume, the mass of the dismantled roof produced can be used to calculate its quantity in container pieces:

$$\rho > \frac{K_k}{V_k} \rightarrow N_t = \frac{q_t}{K_k}$$

The amount of required containers to operate the system can then be determined as a function of the time frame as follows:

$$N_t^* = \sum_{t=1}^{t_{max}} \frac{N_t}{n}$$

If containers can be placed at the disposal sites, the number of containers per disposal site to be moved within the time-frame is as follows:

$$N_f = N_t \cdot x_{t,f}$$

If containers can be placed at the disposal sites, the quantity of containers to be allocated to processing sites can be determined as follows:

$$N_f^* = N_z^* = N_f^* \cdot x_{t,f}$$

Although the main material handling relation in the determination of the collection cost is between the place of origin of the asbestos-containing demolished roofing material and the place of processing, in order to estimate the cost structure more accurately, it is useful to define all transport relations as follows.

The total cost of the collection system is composed of three typical cost elements:

- investment cost of container (K^{CONT}),
- transportation cost (K^{TRAN}),
- investment cost of trucks to transport containers (K^{TRANB}).

Of course, there are many other minor costs that could also be considered in the above model, such as the cost of cleaning and repairing (maintaining) containers. Thus, the total cost can be expressed in the following form:

$$K = K^{CONT} + K^{TRAN} + K^{TRANB}$$

The cost of purchasing containers can then be determined as the sum of all the containers needed in the disposal site:

$$K^{CONT} = \sum_{f=1}^{f_{max}} N_f^* \cdot c_f$$

The transportation cost is calculated on the basis of the mileage of the vehicles:

$$K^{TRAN} = \sum_{f=1}^{f_{max}} \sum_{t=1}^{t_{max}} 2 \cdot l_{t,f} \cdot c_{szall} \cdot x_{t,f} \cdot N_f$$

The investment cost of transport vehicles can be calculated as follows:

$$K^{TRANB} = \sum_{f=1}^{f_{max}} n_f \cdot c_{tranb}$$

The cost model assumes that the collection process uses own containers and is self-operated. The cost of the collection system is defined using the notations in Table I.

Table I.

Definition of notifications

Notification	**Definition**
ρ	average density of asbestos containing roof structure [t/m^3]
q_t	weight of asbestos containing roof structure in settlement t in the predefined time-frame [t]
K_k	upper limit of load of k type container [t]
V_k	net volume of k type container [m^3]
n	available number of collection days within the predefined time-frame
t_{max}	number of settlements integrated into the collection system of asbestos containing roof structure project
V_t	volume of collected asbestos containing roof structures in settlement t [m^3]
N_t	amount of required containers for collected asbestos containing roof structures in settlement t [pcs]
N_t^*	amount of required containers to transport the collected asbestos containing roof structures in settlement t [pcs]
$x_{t,f}$	logical parameter defining the availability of local disposal site: $x_{t,f} = 1$ if disposal site f is assigned to settlement *t* otherwise 0,
N_f	amount of containers assigned to disposal site f [pcs]
N_f^*	amount of required containers required to transport all asbestos containing roof structures to disposal site *f* within the time-frame [pcs]
c_f	specific investment cost of containers for disposal site f [EURO]
c_{tran}	specific transportation cost [EUR/km]
$l_{t,f}$	transportation distance between settlement *t* and disposal site *f* [km]
n_f	number of required transportation vehicles assigned to disposal site *f* [pcs]
c_{tranb}	specific investment cost of one truck to transport containers [EURO]

4. Conclusions

Asbestos-containing roof structures can be found in almost all settlements. The organized change of these roof structures needs well organized logistics systems, where the transportation processes are organized in a financial sustainable way. Within the frame of this article, the author showed a potential algorithm to plan the collection process of used asbestos-containing roof structures and described a simple evaluation method to calculate the transportation related costs.

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