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WASTE COLLECTION AND TREATMENT SYSTEM

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Abstract:
The article deals with a system view of logistic processes within the system of waste collection and treatment in the conditions of the upcoming legislation. The ambition of the authors is to achieve a system that is universally applicable within circular logistics. Such a system is based on existing mostly autonomous systems with the aim of defining a multipurposed and optimized system where individual companies or associations of companies can act as individual subjects in the logistics chain. The authors' approach is based on a system of common defined interfaces in both the handling and transport processes as well as in their information support processes, so that they can be used in the planning of sustainable logistics systems easily.

Key words:
intermodal transport, ACTS, waste processing, RFID, information system, optimization

1 INTRODUCTION

Nowadadys the point of view on supply chain and embedded logistic processes focuses not only on its part from producer/supplier to customer but is extended to full life cycle of any product. The life cycle of a product does not end with its disposal in a landfill, but everything that can still be used becomes part of new products. Not only products themselves follow this but their packaging too (Lingaitienė O. et.al. 2022).

Transportation of used goods/products is important part of the whole transportation (Maharjan M.K., Lohani S.P. 2019), so good logistic can improve efficiency of processes. This demands new attempts in business processes inside and outside of producers and other parties in supply chains (Modi, K. et.al. 2019).

The authors present the first outputs of the project, which will result in a "Methodology for Urban Logistics" with an emphasis on waste management. The intention is to use mixed municipal waste energetically to generate heat as well as electricity. To ensure the efficiency of such a system, it is important that the same transport units - containers - are used across the board for the collection of mixed municipal waste. The developers propose to use ACTS containers with compression equipment. They will be transported from the attraction area to the treatment site by rail.

2 THEORETICAL BACKGROUND

Optimizing the collection and treatment of waste is also important and necessary. Among the most used optimization methods for collection planning is the Clak-Wright method.

The principle of this method is that in each iterative step of the method, two possible routes are selected, if the criteria are met, and combined into a single route in a so-called pooled route. However, it is not possible to combine any routes, only those that satisfy the condition for solving the problem that the sum of the transported volume on the combined route must not exceed the given capacity of the service vehicle. At the same time, it is possible to monitor the fulfilment of other conditions such as the number of nodes visited, the time consumption of the route and the fulfilment of its maximum length. The main advantage of this method of combining routes is the savings that are naturally generated by combining two routes, and we can also measure these savings thanks to the so-called benefit coefficient.

A transport network with $n+1$ nodes (we denote the processing center by u_0 and in addition to this center there will be n customers (waste sources) in the network with demands b_j) can be represented by a graph diagram showing nodes and sections. The values of each section represent the length of the roads that connect the nodes, and the values of the nodes represent the volume of traffic that is demanded during the collection.

To illustrate the formula for calculating the benefit ratio, we first need to know what the initial solution of the Clarke-Wright method looks like, which is a set of shuttle runs.

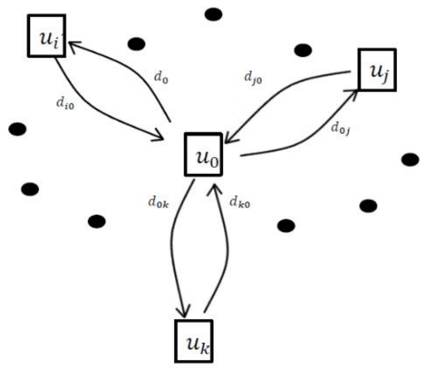

Fig. 1 *Initial solution*

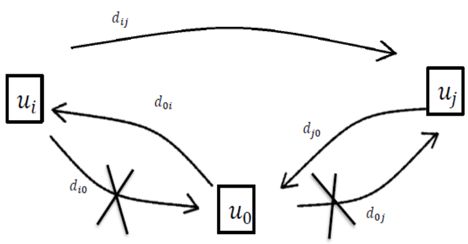

Fig. 2 *Illustration of savings*

Based on Fig. 1 above, it is obvious that if a pair of shuttles is realized, e.g., $u_0 – u_i – u_0 – u_j – u_0$, the distance traveled will be equal:

$$d = d_{0i} + d_{i0} + d_{0j} + d_{j0} \tag{1}$$

If we decide to merge the two shuttles into a round trip on the route $u_0 – u_i – u_j – u_0$, the distance travelled will be equal:

$$d = d_{0i} + d_{ij} + d_{j0} \tag{2}$$

From the representation of the two relations in Fig. 2, it can be seen that in the latter the distances d_{i0} and d_{0j} have been lost, and one distance has been added d_{ij}, which, however, reduces the saving. The gain coefficient that represents the calculation of the saving between nodes u_i and u_j is due to the substitution of the above pair of shuttle trips into one circular trip and has the form:

$$u_{ij} = d_{i0} + d_{0j} - d_{ij} \quad (3)$$

The description of the algorithm itself can be shown in five steps:

- First, the initial solution is composed as a set of shuttle runs.
- In the second step, we compute all the values of u_{ij} and construct the savings matrix.
- The third step is to see if any positive value is contained in the matrix, if there happens to be no positive value in the matrix, the algorithm terminates.
- In the fourth step, we check whether we satisfy the capacity constraint. We check this by selecting the largest value of u_{ij} and test if the sum of the entries is less than or equal to the capacity of the service vehicle ($b_i + b_j \leq K$), if the constraint is satisfied, we can merge the runs into one.
- In the fifth step, we use the largest value we find from the savings matrix and set it equal to zero and return to step 3. (Žáková, M., 2022, Daněk, Teichmann, 2005)

3 RESEARCH METHODOLOGY, DATA AND RESEARCH AREA

The ACTS (Abroll Container Transport System) in intermodal transport is based on the commodity of road and rail freight transport, where it is assumed that rail transport will perform the decisive transport run and road transport will be used for the collection and removal of containers to/from transshipment points. (Sung-Ho Hur, et al, 2020) From these locations the containers will be served by intermodal trains. The ACTS system uses round trips when servicing customers, i.e., picking up mixed waste from collection containers.

Intermodal transport of containers from transshipment points to processing entities can be provided by fast trains running at speeds of 100-120 $km.h^{-1}$ or up to 160 $km.h^{-1}$. For these trains, it is expected that the intermodal transport units will be equipped with satellite positioning systems that will allow customers to monitor their movements and position on the transport network. The regular intermodal trains are operated by night jumps, where the trains depart in the evening and reach their destination the following morning, with the intermodal transport units ready for collection by the consignee by 10 o'clock.

Higher productivity and reliability can be achieved by introducing shuttle trains with a fixed set of rail cars of the same type. Another type can be group trains, which are arranged from car groups of several transshipment points of a certain direction.

In the design of a logistics transport chain system using ACTS, the following requirements are addressed, for which appropriate solutions are sought:

Tab. 1 *Design using the ACTS system*

Requirements	**Solution**
Economical and environmentally friendly circular transport from loading to unloading.	Combined transport by rail - road.
Seamless delivery to various target processors.	Transport of loaded and empty wagons with containers by night jump.
Flexible and rational transshipment, customer service without rail connection.	Rolling containers with horizontal transshipment.
Container capacity, watertight construction.	Development of containers with pressing equipment.

Logistic trends in intermodal transport promote the principle of creating transport chains in which close cooperation between road and rail transport is promoted instead of competition between means of transport:

- Railway vehicles are designed for transporting large volumes of goods and transport units over longer distances according to timetables,
- flexible lorries are mainly intended for the transport of collection containers with mixed waste to the transfer station.

The ACTS system saves operating costs because the handling of the loading units is carried out without the use of capital-intensive vertical handling equipment. Loading and unloading is carried out horizontally by one person - the truck driver.

Advantages of the ACTS roll-off container system:

- Loading and unloading of containers is possible without the use of special vertical transshipment equipment. Handling is possible at each rail track with a defined handling area of at least 10 meters from the rail track axis. Containers may be directly transferred in horizontal position from the railway carriage to the road vehicle and vice versa. Optimal use of the loading space and the loading weight of the vehicles allows for increased transport performance. The reloading can be carried out by the road truck driver within 5 minutes. The handling can be carried out at any accessible location suitable for lowering and sliding the container onto the transport vehicle. The adjustment of the empty support frame for the container on the railway wagon is manual.
- It increases labor productivity because handling as well as transport is carried out by one person. The unified type of road chassis with a manipulator allows the transport and handling of about 15 types of containers designed for the transport of waste materials (paper, glass, plastic, iron, biological waste) for recycling and industrial waste (contaminated soil, ash, sludge).

Technical means of the system:

- Rolling container of standardized design with standardized frame according to EN ACTS standard with dimensions of 2 500 mm width, 5 950 mm length and 2 500 mm height.
- Car carrier equipped with a manipulator, which allows, in addition to the transport itself, the transshipment of the container from and to the railway carriage, car trailer, handling area, unloading of goods by tipping at an angle of 53-57 degrees, safe transport of the container on the car during the transport.
- A flatbed four-axle bogie railcar with swing frames (usually three) for stowing rolling containers at a permissible axle weight of 20 t provides a payload for one container of 16 500 kg.

Currently, the system is used in the Czech Republic for the transport of coal sludge, converter dust, chemical waste, ash, wood chips and other similar substrates. The system is advantageous for the collection of mixed municipal waste with subsequent transport to waste incineration plants. The wider application of the system in practice aims to transfer transport from road to rail, at least in areas of frequent traffic congestion, for the transport of low-value goods, for waste of all kinds and for dangerous goods.

The system of roll-off containers for the collection of mixed municipal waste destined for incineration plants must be introduced in the Czech Republic as a single system. Similarly, this system has been introduced in the countries of the Federal Republic of Germany, Austria, Switzerland, the Netherlands and Italy, as a single system using the same types of containers, car carriers and rail wagons.

4 RESULTS

The law requires municipalities to designate sites for separate collection of certain components of municipal waste. Obligations previously set by decree are now set by law. These include hazardous waste, paper, plastics, glass, metals, biological waste, edible oils and fats and textiles. The implementation of a long-term strategy for the management of waste, packaging waste and end-of-life products is set out in the Waste Management Plan of the Czech Republic, which is approved in its current version until 2024 (Ministry of the Environment, 2022):

- Waste prevention and reduction of specific waste production.
- Minimizing the adverse effects of waste generation and management on human health and the environment.
- Sustainable development of society and transition to a circular economy.
- Maximizing the use of waste as a substitute for primary resources.

To achieve these objectives in a way that meets the requirements and opportunities of the time, appropriate information support is essential to inform all the participants in this logistics chain and to enable optimal decisions to be taken at all points of management.

The following example, which combines both information support and technical solutions for automatic information retrieval, can serve as an example of such a solution. We will focus here mainly on the beginning of the logistics chain, i.e. the points of generation of municipal waste, citizens and companies.

To provide an overview of what type of waste enters the system, it is essential to uniquely identify the waste generator and the collection containers allocated to it (with differentiation for sorting). This initial information stored in the information system is followed by automatic identification of the waste on the individual collection vehicles. This is done by RFID technology, which uniquely identifies, without human intervention, what type of waste is emptied into the collection vehicle (each container is equipped with an RFID tag, see Table 2).

Tab. 2 *RFID tags used*

	For plastic bins	**For metal bins**
Version	Sandwich label	Sandwich tag
Dimensions	100 x 50 mm	150 x 16 x 1.1 mm
Assembly	Self-adhesive	Glue or rivets
Placement	Into the bottom reinforcement	To the bottom edge

The operator of the collection vehicle then only checks whether the actual contents of the container correspond to its intended use and the fill level of the container ($^{0}/_{4}$–$^{4}/_{4}$). An example of the equipment of such a vehicle is shown in Fig. 3.

Each collection truck is equipped with an RFID scanning system, which is set up to remove the RFID tag on the bin or container during the actual emptying process. Combined with analogue sensors that record the physical movement of the tipping mechanism, it is possible to compare the number of bins being tipped with the number of codes read and immediately identify a damaged/missing RFID tag or unauthorized tipping.

The RFID reading itself is performed by an industrial reader with adjustable power and specially adapted antennas. The data and software are housed on an industrial PC with high resistance, as everything is located on the outside of the car body with operating temperatures identical to the outdoor environment.

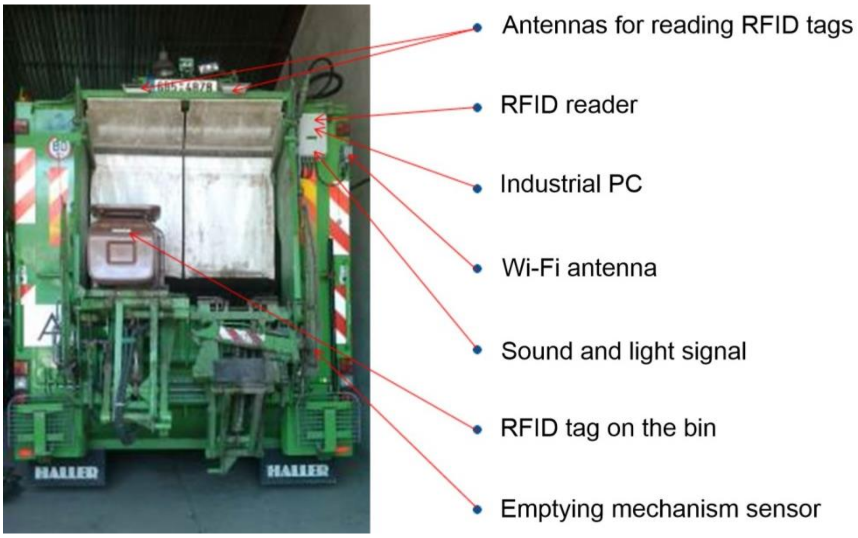

Fig. 3 *ICT on the collection vehicle (Gaben design)*

Upon arrival at the base, the data is automatically transferred over a wi-fi network to a central server. The system is ready to record the GPS coordinates of the dump as well as instant data transfer over the GPRS network. The time of capture and the unique EPC code from the RFID tag memory are transmitted. However, the system is also ready to record the GPS coordinates of the dump as well as instant data transmission via GPRS network. The time of capture and the unique EPC code from the RFID tag memory are transmitted.

Citizens and companies then have access to the information system where they can work with all the necessary information, see e.g. (Vranovice, 2022). The municipality maintains the identification data. These are mainly:

- Address checking/address entry
- Inserting the RFID tag into the register
- Assigning the RFID tag and
- Generating access rights for citizens.

Citizens then have access to Print reports where they can find all the necessary information, especially the score of their waste sorting.

5 CONCLUSION

Presented solution offers the use of a combined transport system with ACTS containers. The system uses the synergistic effects of the individual transport modes, flexibility of road freight transport for collection of mixed municipal waste and parking of loaded containers on the handling area in the railway station. Bulk and timed transport for rail freight in transporting containers to the processing site. The present proposal recommends the widespread (nationwide) introduction of a uniformed system to allow for the transfer of mixed municipal waste to a less used processor when some processing sites are overloaded

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