Scientific Review – Engineering and Environmental Sciences (2018), 27 (1), 19–27
Sci. Rev. Eng. Env. Sci. (2018), 27 (1)
Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska (2018), 27 (1), 19–27
Prz. Nauk. Inż. Kszt. Środ. (2018), 27 (1)
http://iks.pn.sggw.pl
DOI 10.22630/PNIKS.2018.27.1.3

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The cost minimizing solution of the transportation problem for the location of the building machinery yard along the road under construction

Key words: road construction, machinery yard location, optimal location, cost-minimizing, transportation problem, the lowest total distance

Introduction

The problem of minimizing transport cost is currently being solved in almost every branch of industry and commerce. The companies economize in every aspect of their activities in order to be competitive i.e. to survive. The areas of competition are quality of a product, the brand, after-sale service and other. Even if the price level is not a subject to compete (the strong brand and high quality provided are the base of the policy of high prices), economizing on transport cost makes a profit higher. The public sector of the construction industry is a different one. The quality is defined in a tender documentation. The price is the factor that usually influences the most the decision of the client concerning the choice of contractor. Every possibility of cost-lowering gives the potential contractor chance of winning a contract and making the profit (Ahmed, Sultana, Khan & Uddin, 2017). Contractors executing "design and build" contract often suffer from the costs increase arisen from unexpected occurrences (Rybka, Bondar-Nowakowska, Pawluk & Połoński, 2017). Moreover, a very high value of bids for highways construction make savings expressed in fraction of a percent (of a contract value) meaning high monetary value in a profit worked out. As every mean of production has nearly the same price for all contractors, it is necessary for them to search for competitive advantage in an organization of building processes allowing for economizing.

Transportation problem in road construction

On-site machinery yard cost

For the sections of roads being constructed on a new rout the temporary service road is built too. It provides easy access of building machines to the sections of the road being built. The works in progress are protected from the destructive influence of the machines using sublayers of the constructed road for the self-transport to another section being constructed (Biruk, Jaworski & Tokarski, 2009). As the road construction contracts can last in Poland even for several months – sometimes more than 20 (Anysz, 2017a) – and machinery is used every day, it is reasonable to keep the necessary set of construction machines near the building site. The service road allows for every day shifting machinery from the protected (fenced) yard to the subsections of the constructed road. Nevertheless, all these auxiliary (non--productive) activities generate the cost.

Non-productive cost

The yard should be hardened, fenced, equipped with the gate. Temporary access roads should be built allowing for usually everyday self-transport of the machines to the section of the road being built. A contractor has to cover the cost of time of machine operators necessary for everyday transport, that does not create income i.e. time when operators do not erect the construction. The fuel is consumed and machines are used for non-productive self-transport. These costs belong to site overheads (Anysz, 2017b). A part of them cannot be avoided (the yard, access roads), but the optimal location of the yard can be significantly minimized, by the optimal location of the machinery yard.

Effects of cost minimizing

The positive financial effect of cost minimizing is obvious. But shortening the total distance driven by all construction machines from the yard to the places of construction work, makes non-productive time being lower too. Then, time spent by building machine and its operator daily for work execution is longer. All works can be executed during a shorter period of time. Moreover, saved time allow for using machinery on another building site, creating additional financial gain. All effects of properly located machinery yard are shown on Figure 1.

Location of on-site machinery yard

Location of the machinery yard along the road being constructed can be recognized as location-type transportation problem (Diaz-Parra, Ruiz-Vanoye, Loranca, Fuentes-Penna & Barrera-Cámara 2014). The two following methods can be applied in order to find the optimum place for on-site machinery yard:

– the method of the shortest total distance of self-transport (Jaworski, 2009);
– the method of the lowest cost spent on self-transport; developed in this paper.

Modern approach to transportation problem is to transport the goods at minimum global cost (Casquilho & de Miranda, 2017). As for the shortest total distance (STD) method there is the only one solution, as for the lowest cost spent (LCS) method, it is necessary to check: if more than one on-site machinery yard applied, will reduce the total cost of self-

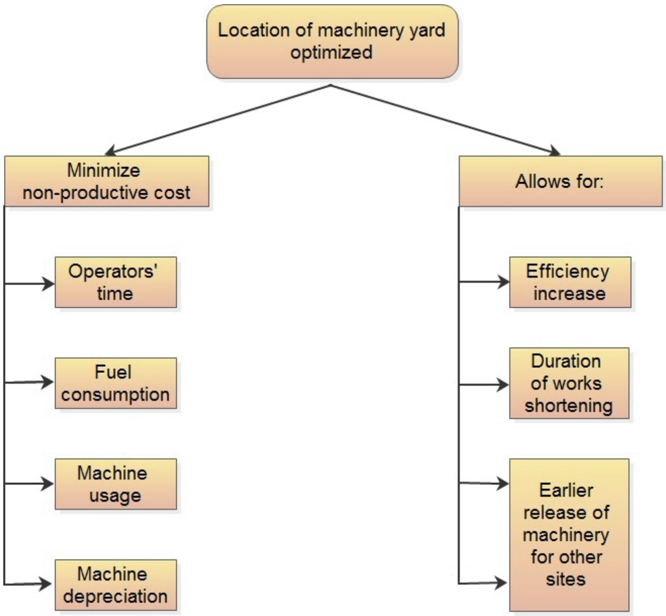

FIGURE 1. Positive effects of optimization of the machinery yard location

-transport. In order to get this information the model of the road construction site has been created.

Solution of transportation problem for the location of the machinery yard

The shortest total distance method

As the temporary access road is usually built along constructed road, the model will be suitable for the case where:

- straight line road was divided into technological sections to be constructed, or
- the root of the road has a polygon shape.

When the root of the road is a curve, the proposed solution will be an approximation only. The location of the machinery yard will be directly near the temporary access road. It was assumed that the road being constructed was divided into n number of technological sections, each of different length – l_i. The access point (from the temporary technological road to the section of the road being constructed) will be in the middle of each section and marked as d_{0i}.

$$d_{0i} = \begin{cases} \frac{1}{2} l_i \ \text{for } i = 1 \\ \frac{1}{2} l_i + \sum_{1}^{i-1} l_i \ \text{for } 1 < i \le n \end{cases} \tag{1}$$

The optimal distance from the beginning of the first section to the center of machinery yard is searched and is marked as x_d (Fig. 2).

There is m-types of building machines. The number of necessary days (a_{ki}) of working of k-type machine on i-section will be given as:

$$\mathbf{a_{mm}} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \tag{2}$$

The matrix **d** can be defined as:

$$\mathbf{d_n} = [d_1\ d_2\ d_3\ \ldots\ d_n] \tag{3}$$

where:

$$d_i = 2\sqrt{(d_{0i} - x)^2} \tag{4}$$

As every machine drive the distance twice a day. Then the total distance (t_d) of self-transport of building machinery can be calculated as:

$$td(x) = \sum_{i=1}^{n} g_i \tag{5}$$

where:

$$g_n = a_{mn} \cdot d_n^T \tag{6}$$

While the total distance is in a fact a linear function of x, it is easy to find x_d that minimize the value of td. Then:

$$\Lambda x \neq x_d \quad td(x) > td\ (x_d) \tag{7}$$

So the optimal location of machinery yard is in the point situated in a distance of x_d from the starting point of the first section (marked as 0 on Fig. 2)

The lowest total cost method

The lowest total distance (given in distance unit) shows the total distance of all building machines drive from the yard to the sections of the road being built during the whole building process. It is a good base for making decision about location of the yard along the road under construction. But it can occur that it is not optimal decision when the criterion of total cost is taken into consideration. In order to calculate the total cost (*tc*) the unit cost (per unit of distance) of self-transport of each kind of machine should be known. As it was shown on Figure 1 the unit cost (uc_k) of self-transport of *k*-type machine can be calculated as:

$$uc_k = op_k + fl_k + w_k + a_k \tag{8}$$

where:

op_k – cost of operator's time per distance unit for *k*-type machine during self-transport;

fl_k – cost of fuel consumed by *k*-type machine during self-transport per distance unit;

w_k – cost of usage of *k*-type machine of during self-transport per distance unit;

a_k – depreciation (cost) of *k*-type machine during self-transport per distance unit.

As every machine has its own economic transportation speed and accord-

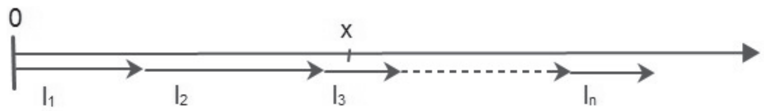

FIGURE 2. Scheme of the model

ing to the unit cost defined in equation (8) the time-cost trade-off (Chakraborty & Chakraborty, 2010) does not exist in analyzed problem The first two sub-strates are easy to evaluate. Every company should know the cost of machine operator, and parameters of the machine they use. It is necessary to distinct cost of machine usage (other than cost of operator and cost of fuel) and depreciation. Depreciation is an accounting term. Within the Polish accounting system (Accounting Law 1994) machine is usually depreciated over 60 months. In every month during this period 1⁄60 of its purchase price (excluding VAT) creates a depreciation (treated as a cost) independently from intensity of the machine usage. After that, when the machine is fully depreciated, monthly depreciation is equal to zero. When the machine is still functional and it is utilized on building sites it requires maintenance (in order to make its functional time longer) – that creates cost. It was assumed that every machine of the same type has the same unit cost (uc_k). Then cost matrix ($\mathbf{c_{mm}}$) can be defined as:

$$\mathbf{c_{mm}} = 2 \cdot \begin{bmatrix} uc_1 \cdot a_{11} & \cdots & uc_1 \cdot a_{1n} \\ \vdots & \ddots & \vdots \\ uc_m \cdot a_{m1} & \cdots & u_{cm} \cdot a_{mn} \end{bmatrix} \tag{9}$$

As for the shortest distance method it was not important that each machine has to drive the distance to the section of road twice, as for cost calculation this fact should be taken into account, because numbers of necessary working days for each machine will be weighted by unit cost. Defining matrix $\mathbf{h_n}$ as:

$$\mathbf{h_n} = c_{mn} \cdot d_n^T \tag{10}$$

the total cost function $tc(x)$ can be set:

$$tc(x) = \sum_{i=1}^{n} h_i \tag{11}$$

The total cost is in a fact a linear function of x it is easy to find x_c that minimize the value of tc. Then:

$$\wedge x \neq x_c \quad tc(x) > tc(x_c) \tag{12}$$

So the optimal location of machinery yard is in the point situated in a distance of x_c from the starting point of the first section (marked as 0 on Fig. 2).

The lowest total cost – the extension

When only one yard has been assumed for a given road construction site, its cost can be omitted in total cost analysis. The yard has to be prepared anyway and cost of this preparation was assumed the same in any location. But in case when

$$tc(x_c) >> y^{(1)} \tag{13}$$

where:

$y^{(1)}$ – cost of preparation one machinery yard together with cost of bringing the terrain to the original look, it can occur that the total cost of self--transport of building machinery (from two machinery yards), even increased by cost of preparing second machinery yard $y^{(1)}$ is lower than $tc(x_c)$. Then – in order to economize – it is reasonable to build one more machinery yard.

The problem of the location of two yards can be solved applying the following procedure:

1. Divide all sections on two group with near the same cost of self-transport of building machines (calculated for one machinery yard).
2. Find the optimal point of location for each group separately using the LTC method described above.
3. Calculate the self-transport cost (for optimal locations) for the first group – $tc^{(1)}\left(x_c^{(1)}\right)$, and for the second too – $tc^{(2)}\left(x_c^{(2)}\right)$.
4. Check the savings (s) using the following formula:

$$s = tc(x_c) - \left[tc^{(1)}\left(x_c^{(1)}\right) + tc^{(2)}\left(x_c^{(2)}\right) + y^{(1)}\right] \tag{14}$$

5. If s is negative – stay with one machinery yard only. If savings are positive – check the inequality:

$$\left(tc^{1}\left(x_c^{(1)}\right) + tc^{(2)}\left(x_c^{(2)}\right)\right) >> y^{(1)} \tag{15}$$

6. If the unevenness (15) is false – stay with two machinery yards. If equation (15) is true – continue with dividing for more groups of sections, continuing checking savings and the condition (15). In this case, equations (14) and (15) should be modified to compare cost of a new variant (p – locations of machinery yard) with cost of previously analyzed variant (p – locations of machinery yard).

Validation of LTC and LTCE based on the example

The planned road of the total length 23 km has been divided into 4 sections having following lengths: 5, 7, 3 and 8 km. There were 6 types of building machine involved and for them:

$$\mathbf{a} = \begin{bmatrix} 12 & 14 & 18 & 82 \\ 15 & 52 & 13 & 98 \\ 14 & 9 & 12 & 75 \\ 16 & 20 & 11 & 83 \\ 18 & 25 & 12 & 87 \\ 22 & 44 & 25 & 90 \end{bmatrix}$$

Calculation of the shortest total distance using STD procedure has produced that for x_d = 19 km the total distance is minimal – $\min(td(x_d))$ = 7,646 km. It can be seen on Figure 3.

In order to apply LTC procedure the cost matrix should be set:

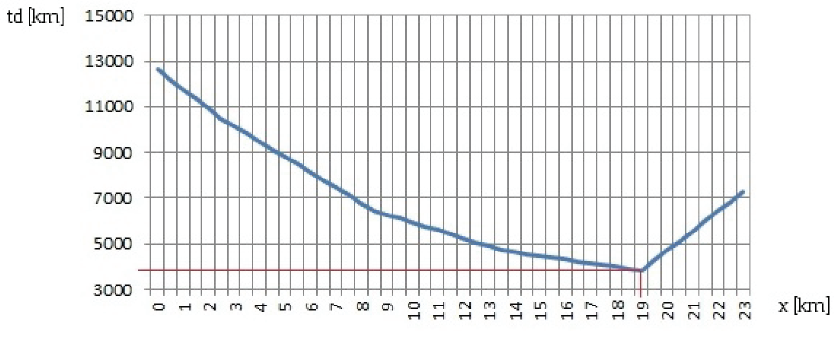

FIGURE 3. The total distance (td) as a function of the location of machinery yard

$$\mathbf{c} = 2 \cdot \begin{bmatrix} 11 \cdot 12 & 11 \cdot 14 & 11 \cdot 18 & 11 \cdot 82 \\ 8 \cdot 15 & 8 \cdot 52 & 8 \cdot 13 & 8 \cdot 98 \\ 5 \cdot 14 & 5 \cdot 9 & 5 \cdot 12 & 5 \cdot 75 \\ 7 \cdot 16 & 7 \cdot 20 & 7 \cdot 11 & 7 \cdot 83 \\ 4 \cdot 18 & 4 \cdot 25 & 4 \cdot 12 & 4 \cdot 87 \\ 9 \cdot 22 & 9 \cdot 44 & 9 \cdot 25 & 9 \cdot 90 \end{bmatrix}$$

Now the unit prices of each type of machine usage per kilometer are taken into account. The lowest total cost – $\min(td(x_c))$ = 57,335 [monetary unit], was calculated for x_d = 19 km. The shape of $tc(x)$ is the same as $td(x)$ – Figure 4. The result i.e. optimal location of machinery yard is the same too. Nevertheless, the result achieved from LTC – in monetary units – can be compared with cost preparing additional machinery yard. Then rational decision can be taken out: to build one or two yards (together with their optimal locations).

Applying LTCE the sections of constructed road were divided into two groups: section 1 and 2, section 3 and 4. The optimal locations and the lowest total cost were calculated separately for each group. The results achieved are as follows:

$$x_c^{(1)} = 8.5 \text{ [km]}$$

and $tc\left(x_c^{(1)}\right) = 8,448$ [monetary units]

$$x_c^{(2)} = 15.5 \text{ [km]}$$

and $tc\left(x_c^{(2)}\right) = 7,832$ [monetary units]

Organizing two yards instead of one, lowers the transportation cost to 28.4% of its original value (for the values assumed in this example). Savings can be calculated now as:

$$s = 57,335 - [8,448 + 7,832 + y^{(1)}]$$

If $s \leq 0$ only one yard should be prepared. If $y^{(1)} < 20,527.5$, savings arising from organizing two machinery yards in optimal locations will be achieved. When $y^{(1)} << 16,280$, the variant with one more yard should be checked according to described above procedure (LTCE).

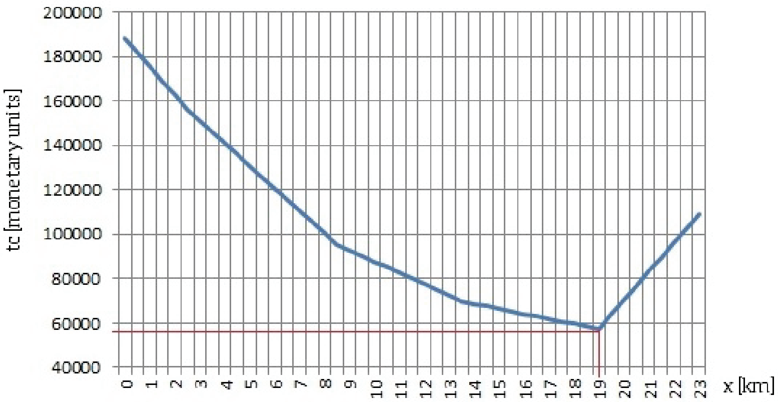

FIGURE 4. The total cost (tc) as a function of the location of machinery yard

Conclusions

The shortest total distance (STD) method of finding optimal location of machinery yard along the road under construction gives the same result as the lowest total cost (LTC) method. Nevertheless STD method is not sufficient for determining if higher savings can be achieved. Applying LTCE procedure, it is possible to find cheaper solutions, i.e. finding:

– how many machinery yards should be located along the road under construction,
– what are their optimal locations along the road under construction,
– what amount of money can be saved comparing to one machinery yard organized (even if cost of additional yards are spent).

Analyzed methods can be applied for the straight road being built, the road of polygon shape as exact methods. When the road has a shape of a curve it is necessary to find the lengths of its sections, and STD or LTC (LTCE) can be applied as well with some approximation. It is to emphasize that one of aforementioned methods has to be used. Choosing the location of machinery yard in the location where the sum of distances from the yard to middle points of the sections (without taking into account number of machines, number of their working days) gives other location of the machinery yard. In this case the total cost of self-transportation will increase (for the example calculated 166%). The numbers (distances, number of days, prices) were assumed for the calculations purposes and STD and LTC (LTCE) methods should be verified the real construction site data. Application of LTC(E) provides cost savings, but simultaneously time savings (as financially optimal location of machinery yard gives the shortest total distance of self-transport of building machinery), so it significantly increase the efficiency of a road construction project. As the competitive market requires cost minimizing without economizing on quality of goods or services the precise unit transportations cost of self-transport of building machinery is necessary. Methods LTC and LTCE optimize the transportation cost based on these precise unit prices.

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Summary

The cost minimizing solution of the transportation problem for the location of the building machinery yard along the road under construction. This paper presents costs arisen from every-day transport of building machinery from the yard located by the road being constructed to the place of work. These costs are not directly associated with the income creating. The optimal choice of the place for the machinery yard can substantially lower these costs. The following two methods of finding the optimal place were proposed: based on the shortest distance and based on the lowest cost of building machinery self--transport. They were calculated for the exemplary data. Applying the method based on the lowest cost allows finding more than one location of machinery yard. The cost of applying more than one yard can reduce much more the costs of construction site.

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