METHOD OF CALCULATING A COMBINED TRANSPORT SYSTEM

ILDIKO BRÎNAŞ[1]

Abstract: In the specialized literature, efforts have been made to define multimodal transport. Thus, multimodal transport refers to the transportation of goods carried out using at least two different modes of transport, based on a multimodal transport contract. This begins at a location in the state where the goods are received by the multimodal transport operator and ends at the designated delivery location in a different state. The transport contract is concluded between the consignor and the multimodal transport operator, who acts on their own behalf and assumes responsibility for fulfilling the contract. In the following sections, I aim to present a calculation model for designing a multimodal transport system of the road–rail type.

Keywords: combined transport, road, rail, multimodal, system.

1. THEORETICAL CONCEPTS

Multimodal transport systems represent a reliable alternative for the future as they best address increasingly stringent demands for the decongestion of roadways, environmental protection, and energy conservation—critical aspects for humanity's progress. At the same time, they meet the ever-growing requirements of transport beneficiaries in terms of the range and quality of services provided.

A characteristic of multimodal transport is the synergy achieved between the ability to transport goods over long distances offered by rail transport and the flexibility provided by road transport for short distances.

Quantitatively, transport is experiencing significant growth. Meeting the needs of goods exchange, supplying major consumers, often over long distances, highlights transport as a tool for progress and an essential criterion for economic development.

For designing a multimodal freight transport system of the road–rail type for the A – B route with transshipment at terminal T (Figure 1), the following initial calculation data will be considered:

[1] *Assoc. Prof. Ph.D. Eng., University of Petroşani, kerteszildiko@ymail.com*

Fig. 1. Multimodal transport route

a) Transport volume from A to B:

$$Q_a^E = 160256\left[\mathrm{t}\right] \tag{1}$$

b) Transport volume from B to A:

$$Q_a^S = 150240\left[\mathrm{t}\right] \tag{2}$$

c) Average speed of road transport:

$$v_t^a = 30\left[\frac{\mathrm{km}}{\mathrm{h}}\right] \tag{3}$$

d) Average speed of rail transport:

$$v_t^{CF} = 50\left[km\right] \tag{4}$$

2. CALCULATION OF TRANSPORT VOLUME

The total quantity of goods that has to be transported daily on distances A – B and B – A will be:

$$Q_z = \frac{Q_a \cdot \mu_T}{z_{an}^{lucr}}\left[\frac{\mathrm{t}}{\mathrm{day}}\right] \tag{5}$$

where:

Q_a – represents the annual quantity of goods;

z_{an}^{lucr} – represents the number of working days in a year;

μ_T – total unevenness coefficient;

$\mu_T = \mu_s \cdot \mu_L \cdot \mu_z$

$\mu_S = 1.2 \div 1.3$

μ_L – monthly unevenness coefficient;

$\mu_L = 1.001 \div 1.002$

μ_z – daily unevenness coefficient;

$\mu_z = 1.10 \div 1.15$

$\mu_T = \mu_s \cdot \mu_L \cdot \mu_z = 1.2 \cdot 1.001 \cdot 1.10 = 1.32$

$z_{an}^{lucr} = 365 - (2 \cdot 52) - 11 = 250$ days

We obtain the following quantities:

- on distance A – B

$$Q_z^E = \frac{160256 \cdot 1.32}{250} = 846.15 \text{ [t/ day]} \tag{6}$$

- on distance B – A

$$Q_z^S = \frac{150240 \cdot 1.32}{250} = 793.26 \text{ [t/ day]} \tag{7}$$

The calculated quantities are summarized in table 1.

Table 1 **Total quantity of goods**

Distance [km]	**Annual quantity Q_{an} [t]**	**Daily quantity Q_z [t]**
A – B (E)	160256	846.15
B – A (S)	150240	793.26
TOTAL	310496	1639.41

3. CALCULATION OF THE NUMBER OF CONTAINERS

From the existing container types in table 2, the same type of container will be used throughout the entire multimodal transport chain. The container type 1C-20’ is chosen, and the required number of containers is calculated using the standard equation.

Table 2 **Main characteristics of containers**

Category	**External dimensions**			**Tare weight [t]**	**Useful weight [t]**	**Useful volume [m³]**	**Total weight [t]**
	L **(mm)**	***l*** **(mm)**	***h*** **(mm)**				
1A – 40’	12192	2438	2438	2.3	28.20	65	30.5
1B – 30’	9143	2438	2438	1.80	23.60	48	25.4
1C – 20’	6058	2438	2438	1.50	18.90	31	20.4
1D – 10’	3097	2438	2438	1.30	8.90	15	10.2

$$N_{c/z} = \frac{Q_a \cdot \mu_T}{z_{an}^{lucr} \cdot q} = \frac{Q_z^{max}}{G_i \cdot \gamma} \tag{8}$$

where:

$N_{c/z}$ – represents the required number of containers per day;

$Q_z^{\max}$ – represents the daily quantity of goods;

G_i – represents the useful weight of the selected container;

$G_i = 18,9\,\text{t}$

γ – utilization coefficient of the transcontainer's useful capacity;

$q = G_i \cdot \gamma$

$\gamma_F = 0,7$

Considering that we have the same number of containers on both A – B and B – A routes, the utilization coefficient of the useful capacity of the container on the B – A route, denoted by γ_s will be calculated using the following formula:

$$N_{c/z}{}^{E} = N_{c/z}{}^{S} \tag{9}$$

We obtain:

$$\frac{Q_z^{\max(E)}}{G_i \cdot \gamma_E} = \frac{Q_z^{\max(S)}}{G_i \cdot \gamma_S} \Rightarrow \frac{846.15}{797.54} = \frac{\gamma_E}{\gamma_S} \Rightarrow 1.066 = \frac{\gamma_E}{\gamma_S} \Rightarrow \lambda_S = \frac{\gamma_E}{1.066} \Rightarrow \frac{\gamma_E}{\gamma_S} = 0.656 \tag{10}$$

- on the distance A – B

$$N_{c/z}^{E} = \frac{846.1}{0.7 \cdot 18.9} = 63.95 \approx 64 \,\text{containers} \tag{11}$$

- on the distance B – A

$$N_{c/z}^{S} == \frac{793.26}{0.656 \cdot 18.9} = 63.98 \approx 64 \,\text{containers} \tag{12}$$

Table 3. **Main characteristics of wagons for container transport**

No.	**Wagon series**	**Number of axles**	**Dimensions [mm]**			**Tare weight [t]**	**Load capacity [t]**	**Max. weight [t]**	**Max. speed [km/h]**
			L	l	H				
1	Kwm	2	10040	2800	1240	10	15	12.5	100
2	Rp	4	18300	2700	1270	26.4	40	66.4	100
3	Rmms	4	12800	3100	1200	25.1	56	81.1	100
4	Rgx	4	22000	2500	1265	23	57	80	100

A type of wagon from the Rgx series is selected for loading the containers.

4. CALCULATION OF THE REQUIRED NUMBER OF WAGONS

This is calculated using the equation:

$$N_{vag} = \frac{N_{c/z}}{2} [\text{wagons}] \tag{13}$$

where:

N_{vag} – is the required number of wagons;

$N_{c/z}$ – represents the daily number of containers;

$N_{c/z}{}^{E} = N_{c/z}{}^{S} = 64$ – represents the total number of containers;

2 – is the number of containers loaded on the wagon;

$N_{vag} = \frac{N_{c/z}}{2} = 64/2 = 32$ – represents the number of wagons.

Table 4. **Required number of wagons**

Direction	**Q_{an} [t]**	**Q_z [t]**	**N_t [wagons]**	**N_{vg} [vg]**
A – B	160256	846.15	64	32
B – A	150240	793.26	64	32
Total	310496	1639.41	128	64

5. ESTABLISHING THE TRAFFIC SCHEDULE

The transport task formulated by the consignor is carried out in a combined road-rail system. Since the client works only 5 days a week and has a day shift schedule (6:00-16:00), the working hours at the terminal and the container shuttle train schedules must be aligned with this program as follows:

- Containers trains will arrive at the terminal between 6:00-9:00 and depart about 14:00-16:00;
- The entire activity at the terminal will be carried out according to the arrival and departure times of the container trains, based on the schedules.

To achieve this program, the entire activity – from the client's operations to road transport, terminal activities, and rail transport – must be strictly coordinated.

For transporting 20' containers to and from clients, between the clients and the terminal, a VOLVO flatbed truck is used, with a specific diesel consumption of $20 \text{ l}/100 \text{km}$, a loading capacity of $G_i = 21 \text{t}$, a platform length of 8 m, and a platform width of 2.5 m.

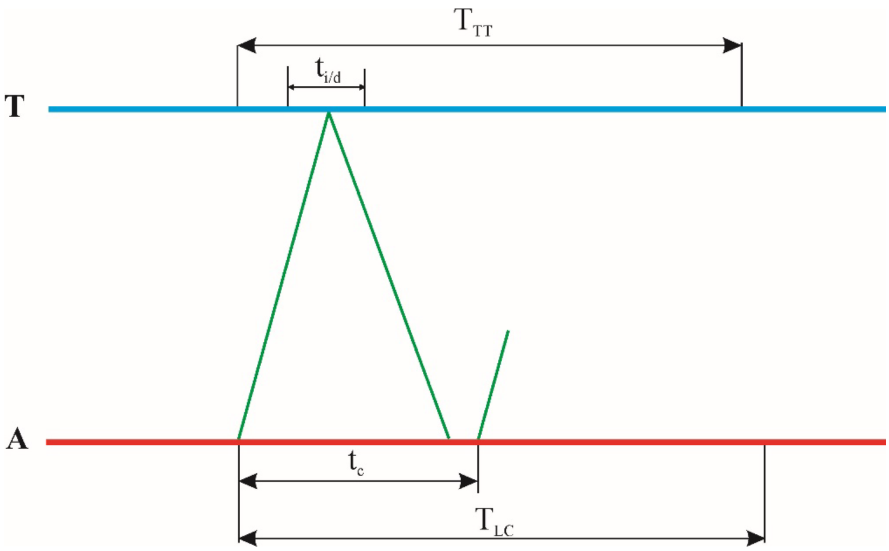

Fig. 2. Working time

The working time is shown in figure 2, with the notations as follows:

T_{LC} – is the working time at the client;

t_c – is the duration of a cycle (for the first loaded truck);

$t_{i/d}$ – loading-unloading time;

$t_{i/d} = t_i + t_d$;

$t_{i/d} = 10\,\text{min}$;

t_i – loading time;

t_d – unloading time;

$t_i = t_d = 300\,\text{s} = 5\,\text{min}$;

In case of double operations $t_{i/d} = \sum_{1}^{N_c} t_{i/d}$;

T_{TT} – is the working time at the terminal.

6. CALCULATION OF THE VEHICLE FLEET

The vehicle fleet is composed of an inventory fleet, an active fleet, and an immobilized fleet.

The active fleet, P_A – represents the number of vehicles required for transport;

The inactive fleet, P_{in} – represents the fleet that is immobilized due to the following reasons:

a) Technical reasons - P_{in}^{T} ;

b) Organizational reasons - P_{in}^{O};

c) Force majeure reasons and both foreseen and unforeseen causes - P_{in}^{F}.

Active fleet:

$$P_A = \frac{t_c}{t_{i/d}} \text{vehicles} \tag{14}$$

where:

t_c – is the duration of a cycle; this is calculated as:

$$t_c = t_i + t_{A-T} + t_d + t_d + t_i + t_{T-A} + t_d \tag{15}$$

$t_{A-T} = t_{T-A}$ – is the transport time from the client to the terminal and vice versa; this is calculated using the formula:

$$t_{T-A} = t_{A-T} = \frac{d_t^r}{v_t^r} \tag{16}$$

d_t^r – is the distance from the client to the transport terminal;

v_t^r – truck speed;

For the calculations, the following values are selected for distance: $d_t^r = 40\,\text{km}$ and truck speed: $v_t^r = 30\,\text{km/h}$. Based on these values, the results of the calculations are as follows:

$$t_{T-A} = t_{A-T} = \frac{d_t^r}{v_t^r} = \frac{40}{30} = 1.33\,\text{h} = 80\,\text{min} \tag{17}$$

where:

t_i – loading time;

t_d – unloading time;

For $t_i = t_d = 300\,\text{sec} = 5\,\text{min}$, the resulting duration of a cycle is:

$$t_c = t_i + t_{A-T} + t_d + t_i + t_{T-A} + t_d = 180\,\text{min} \tag{18}$$

and the needed active fleet becomes:

$$P_A = \frac{t_c}{t_{i/d}} = \frac{180}{10} = 18 \text{ active vehicles.} \tag{19}$$

Calculations of the distance traveled by active vehicles in one day:

$$L_z = P_A \cdot n_{c/z} \cdot lc \tag{20}$$

where:

L_Z – is the daily distance traveled by active vehicles;

lc – is the length of one trip, which is this is calculated as:

$$lc = 2 \cdot d_t^r = 80\,\text{km} \tag{21}$$

$n_{c/z}$ – is the number of the trips per day; this is determined using the formula:

$$n_{c/z} = \frac{t_{1/z}}{t_c} \tag{22}$$

where:

$t_{1/z}$ – working time per day;

$t_{1/z} = 8h = 480\,\text{min}$

$n_{c/z} = \frac{t_{1/z}}{t_c} = \frac{480}{180} = 2.66 \cong 3\,\text{trips}$

$L_z = P_A \cdot n_{c/z} \cdot lc = 18 \cdot 3 \cdot 80 = 4.320\,\text{km}$

Inactive fleet

$$P_{in} = \frac{\left(P_{in}^{\ T} + P_{in}^{\ O} + P_{in}^{\ F}\right)}{z_{an}^{\ lucr}} \tag{23}$$

where:

$z_{an}^{\ lucr}$ – represents the number of working days in the year;

$z_{an}^{\ lucr} = 250\,\text{days}$;

$P_{in}^{\ T}$ – annual immobilized vehicle fleet due to technical reasons;

$P_{in}^{\ O}$ – annual immobilized vehicle fleet due to organizational reasons;

$P_{in}^{\ F}$ – annual immobilized vehicle fleet due to force majeure;

$P_{in}^{\ T} = P_{in}^{\ RT} + P_{in}^{\ RC1} + P_{in}^{\ RC2}$

$P_{in}^{\ T} = 10 \div 20\% \cdot P_{in}^{\ T}$

$P_{in}^{\ T} = 1.5 \div 2.0\% \cdot P_{in}^{\ T}$

$P_{in}^{\ RT}$ – annual inactive fleet under technical revision;

$P_{in}^{\ RC1}$ – inactive fleet under annual Grade I;

$P_{in}^{\ RC2}$ – inactive fleet under annual Grade II;

l_{RT} – distance after which technical revision is performed;

$l_{RT} = 10.000\,\text{km}$;

l_{RC1} – distance after which Grade I repairs are performed;

$l_{RC1} = 20.000\,\text{km}$;

l_{RC2} – distance after which Grade II repairs are performed;

$l_{RC2} = 30.000\,\text{km}$;

t_{RT} –duration of immobilization during technical revision;

$t_{RT} = 1\,\text{day}(8\,\text{hours})$;

t_{RC1} –duration of immobilization during Grade I repairs;

t_{RC1} – 3 days (24 hours);

t_{RC2} – duration of the immobilization during Grade II repairs;

t_{RC2} – 5days (40 hours);

Based on these values, we calculate the immobilized fleet under technical revisions and annual grades I and II as:

$$P_{in}^{RT} = \left(\frac{La}{l_{RT}} \cdot t_{RT}\right) \cdot \frac{1}{t_{1/z}} = \left(\frac{250 \cdot 4320}{10000} \cdot 8\right) \cdot \frac{1}{8} = 108\,\text{revisions} \tag{24}$$

$$P_{in}^{RC1} = \left(\frac{La}{l_{RT}} \cdot t_{RT}\right) \cdot \frac{1}{t_{1/z}} = \left(\frac{250 \cdot 4320}{20000} \cdot 24\right) \cdot \frac{1}{8} = 162\,\text{revisions} \tag{25}$$

$$P_{in}^{RC2} = \left(\frac{La}{l_{RT}} \cdot t_{RT}\right) \cdot \frac{1}{t_{1/z}} = \left(\frac{250 \cdot 4320}{30000} \cdot 40\right) \cdot \frac{1}{8} = 180\,\text{revisions} \tag{26}$$

So, the resulting values for annual immobilizations becomes:

- $P_{in}^{T} = P_{in}^{RT} + P_{in}^{RC1} + P_{in}^{RC2} = 108 + 162 + 180 = 450$ annual immobilizations due to technical reasons;
- $P_{in}^{O} = 10\% \cdot P_{in}^{T} = 0.1 \cdot 450 = 45$ annual immobilizations due to organizational reasons;
- $P_{in}^{F} = 1.5\% \cdot P_{in}^{T} = 0.015 \cdot 450 = 6.75 \approx 7$ annual immobilizations due to force majeure;

In conclusion, the total inactive fleet resulted is:

$$P_{in} = \frac{\left(P_{in}^{T} + P_{in}^{O} + P_{in}^{F}\right)}{z_{an}^{lucr}} = \frac{450 + 45 + 7}{250} = 2.008 \cong 3 \tag{27}$$

The total inventory fleet is P_i expressed as:

$$P_i = P_A + P_{in} \tag{28}$$

where:

P_i – Inventory fleet;

P_A – Active fleet; $P_A = 18\,\text{vehicles}$;

P_{in} – Inactive fleet; $P_{in} = 3\,\text{vehicles}$;

$P_i = P_A + P_{in} = 18 + 3 = 21\,\text{vehicles}$

Calculation of the distance traveled by a vehicle in one day:

$$l_{mz} = n_{c/z} \cdot lc \tag{29}$$

where:

l_{mz} – daily distance traveled by an active vehicle;

$n_{c/z}$ – number of trips per day;

$n_{c/z} = 3\,\text{trips}$;

lc – length of one trip;

$lc = 2d_t^r = 80\,\text{km}$;

$l_{mz} = n_{c/z} \cdot lc = 3 \cdot 80 = 240\,\text{km/ days}$

CONCLUSIONS

Multimodal transport is considered a secure alternative for the future, as it best meets both the increasingly pressing requirements for decongesting roadways, protecting the environment, and conserving energy, as well as the growing demands of transport beneficiaries regarding the range and quality of services.

The largest standardized cargo unit is the container, which allows for the grouping and securing of packaged goods placed on pallets, thus serving as both packaging and a shipping unit.

From a technical perspective, the standardization of the container allows for easy "linking" between the transport means involved in the transport chain, ensuring the rapid flow of door-to-door transport.

Considering that containerized transport is multimodal, and that intercontinental exchanges require the use of at least two distinct modes of transport, using a container when dispatching a load greatly simplifies the repeated handling and storage operations, helps reduce stock levels, and minimizes the risks of loss, damage, or theft of cargo.

Therefore, the container can also be seen as a mobile warehouse; while the goods are "stored" in the container, they are simultaneously heading toward the recipient, thus reducing both stock sizes and storage requirements.

In rail transport, containerization reduces the workload at classification stations, increases the commercial speed of trains, and raises the turnover of freight wagons by 20-25%.

In road transport, containerization facilitates significant savings in investments by simplifying the construction of transport means and making better use of traction equipment.

In short, the loading and unloading operations of a container with goods previously stacked in it are reduced to 2-3 minutes compared to 3 hours, which were required in the case of conventional transport.

REFERENCES

[1]. **Alexa C.** *Transporturi si expeditii internationale*, Editura All, Bucuresti, 1995.

[2]. **Chisăliță I., Shahmehri N.** *A novel architecture for supporting vehicular communication.* IEEE 56th Vehicular Technology Conference, Vancouver, Canada, pg.1002-1006, September 2002.

[3]. Product technical documentation and standards for: Motorola, Wavecom, Garmin, Alcatel, Siemens, Ericsson, Raytheon, Racall-Decca, J.R.C., Navtronics, Foruno-Electric Co. Ltd., RES Radar GmbH, GSM. Association, 2001

[4]. **European Transport Safety Council (ETSC).** *Intelligent Transportation System and Road Safety Report.* Brussels, Belgium, 1999.

[5]. **Iliescu, M.** *Trafic şi autostrăzi*, Cluj-Napoca, Litografia universităţii Tehnice Cluj-Napoca, 1999.

[6]. Integrarea sistemelor de ghidare dinamică a rutei şi de control al traficului, 2002, http://www.cordis.lu/.

[7]. **Miller R, Huang Q.** *An adaptive peer-to-peer collision warning system*, IEEE Vehicular Technology Conference, p.317-321, Birmingham, USA, may 2002.

[8]. **Milliken, R.J., Zoller, C.J.** *Principle of Operation of NAVSTAR and System Characteristics*. GLOBAL POSITIONNING SYSTEM Papers, Vol. I: Navigation", The Institute of Navigation, Washington D.C., S.U.A.,1979.

[9]. **Pereş, GH., Untaru, M., Seitz, N., Popa, G.** *Teoria traficului rutier şi siguranţa circulaţiei*, Braşov, Ed. Univ. din Braşov, 1982

[10]. **Nemţanu, F.C.** *Arhitectura Sistemelor Inteligente de Transport – ITS*, revista Transurb, nr.1/2003 pp.18, ISSN 1582 -4500.

[11]. **Radu, S. M., Popescu, F. D., Andras, A., Kertesz (Brînaş), I., Tomus, O. B.** *Simulation and modelling of the forces acting on the rotor shaft of BWEs, in order to improve the quality of the cutting process.* Annals of the University of Petroşani, Mechanical Engineering, Vol. 20, pp. 63-72, (2018).

[12]. **Nemţanu,F.C., Minea, M., Bureţea, D.,** *The Intelligent Transportation Systems and Services (ITS) a Main Component of Information Approach of Society: The Development of the ITS on the Base of National ITS Architecture*, International Conference on Computers and Communications ICCC 2004, 27-29 May, Baile Felix Spa – Oradea Romania, University of Oradea, proceedings, pp. 267-271.

[13]. Sisteme inteligente de transport, 1999 – 2001, "Rapoarte şi cercetări naţionale"

[14]. Sisteme inteligente de transport, 2002,http://dir.yahoo.com/Business_and_Economy

[15]. http://www.e-transport.ro/CONTROL_TRAFIC-3.html

[16]. **Kovacs, I., Andraş, I., Nan, M.S., Popescu, F.D.** *Theoretical and experimental research regarding the determination of non-homogenons materials mechanical cutting characteristics*. 8th WSEAS International Conference On Simulation, Modelling And Optimization (SMO '08) Santander, Cantabria, Spain, September 23-25, 2008.

[17]. Popescu, F.D., Radu, S.M., Andraş, A., Brînaş, I. *Numerical Modeling of Mine Hoist Disc Brake Temperature for Safer Operation.* Sustainability, 13, 2874, 2021. DOI: 10.3390/su13052874.

[18]. Andraş, A., Brînaş, I., Radu, S.M., Popescu, F.D., Popescu, V., Budilică, D.I. *Investigation of the Thermal Behaviour for the Disc-Pad Assembly of a Mine Hoist Brake Using COMSOL Multiphysics.* Acta Tech. Napoc.-Ser. Appl. Math. Mech. Eng. 2021, 64, 227–234.

[19]. Popescu, F.D., *Aplicaţii industriale ale tehnicii de calcul*, Editura AGIR, Bucureşti, 2009.

[20]. Popescu, F.D. *Calculatorul numeric în industria extractivă*, Editura Universitas, Petroşani, 2004.

[21]. Popescu, F.D. Radu, S.M. V*ertical Hoist Systems: New Trends Optimizations*. LAP Lambert Academic Publishing, 2013

[22]. I. Mitran, F.D. Popescu, M.S. Nan, S.S. Soba, *Possibilities for Increasing the Use of Machineries Using Computer Assisted Statistical Methods*, WSEAS Transactions on Mathematics, Issue 2, Volume 8, February 2009.