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# COMPUTER APPLICATION SYSTEM FOR OPERATIONAL EFFICIENCY OF DIESEL RAILBUSES

**Abstract**

*The article presents a computer algorithm to calculate the estimated operating cost analysis rail bus. This computer application system compares the cost of employment locomotive and wagon, the cost of using locomotives and cost of using rail bus. An intensive growth of passenger railway traffic increased a demand for modern computer systems to management means of transportation. Described computer application operates on the basis of selected operating parameters of rail buses.*

## 1. SUBURBANAND REGIONAL RAIL SERVICES

Until recently, regional rail services were operated by electric three-car multiple units, EN57 and EN71, as well as SP42 or SM32 diesel locomotives to haul up to four cars on non-electrified routes. The aforementioned electric or diesel trains were heavy vehicles with high axle loads ranging from 160÷170 kN. These vehicles had numerous shortcomings, including high energy consumption, lack of operational reliability, low acceleration (1.2 m/s$^2$), lack of smooth

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running due to noise and vibration on a vertical and horizontal plane, low braking rate, low travel comfort (lighting, heating), inefficient and usually non-operational sanitary facilities which are difficult to maintain clean. In addition, these units did not have train destination side plates, which made orientation difficult for passengers getting on and out of the train from side travel directions. Passengers also reported difficulties with getting on and out of trains at high-platform stations. The use of standard train sets led to destruction of railway tracks, the technical condition of which was and still is far from being satisfactory, high consumption of electric energy and diesel oil, as well as degradation of the environment due to vibration, noise and pollution. The above factors contributed to the development of modern multiple units based on modern computer systems with new, passenger-friendly constructional and operational parameters which meet EU requirements (Sobaszek, Gola & Świć, 2014).

Suburban and regional rail services at distances of approx. 150 km on electrified lines with a higher traffic density are operated by electric multiple units EN 57.On secondary non-electrified lines (it is estimated that there are about 6500km of such lines), the traffic is operated by SM42, SP42 and SP32 diesel locomotives with two or three second-class passenger cars.

The PKP Polish Railways plans to close these lines down due to their unprofitability. Apart from low commercial speed of trains on secondary lines, the operation of rail traffic using diesel locomotives is very expensive.

This cost can significantly be reduced if a locomotive, e.g. SP42 with two cars, is replaced with a railbus, e.g. Regio Tramp 215M (two-unit) or 213M (single-unit).

Compared to diesel locomotives, the use of the above railbuses brings the following benefits (Stokłosa & Cisowski, 2008; Cisowski & Wojciechowski, 2011):

- the cost of materials, operation and maintenance of a high-speed engine manufactured by MAN (such engines are applied in Regio Tramp 215M and 213M buses) are lower than the cost of materials, operation and maintenance of a diesel engine type a8C22 (used in SP42 locomotives),
- fuel and engine oil consumption by 2 engines of a 210M railbus is by 13% lower than that by the a8C22 engine.

The operational costs of a railbus are significantly lower than those of the analyzed trainset due to a lower railbus weight and thus its lower impact on the track.

The data listed in the above table demonstrate that the number of passengers in both cases is almost the same, but fuel consumption is much lower in the case of railbuses (Dębiński, Kiercz, Kowalski & Kądziołka, 2011).

In addition, travel comfort in railbuses is higher. Finally, the lower weight of railbuses means that the rail tracks are destroyed to a smaller extent.

Table 1 provides a comparison of the operational parameters of two Regio Tramp railbuses and an SP42 locomotive.

**Tab. 1. Comparison of a railbus and SP42 locomotive with two cars used in computer algorithm (own study)**

| Type of trainset or railbus | Unit | SP42 locomotive +2 cars 120A | Regio Tramp 215 | %215 M/ SP42 |
|---|---|---|---|---|
| Weight | [t] | 159.5 | 58 | 36 |
| Number of passengers | [pc] | 128 | 120 | 94 |
| Weight of passengers | [t] | 8.96 | 8.4 | 94 |
| Engine type | - | A8C22 | 2x2866LUH-21 | - |
| Number and arrangement of cylinders | - | 8V50° | R6 | - |
| Rated power | [kW] | 588 | 2x250 | 85 |
| Rated rotational speed | [1/min] | 1000 | 2000 | - |
| Rated fuel consum./unit | [g/kWh] | 224 | 195 | 87 |
| Engine oil consumption | [g/kWh] | 1.12 | 1.135 | 101 |
| Fuel consumption in normal conditions | [kg/h] | 131.7 | 114.5 | 37 |
| Engine oil refill consumption | [kg/h] | 0.659 | 0.244 | 37 |
| Idle-run fuel consumption | [kg/h] | 9.0 | 2x2.2 | 49 |

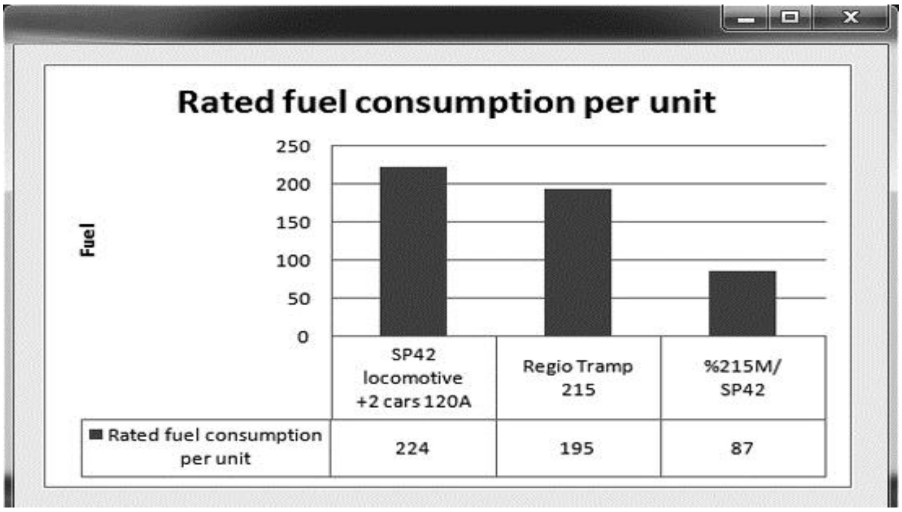


**Fig. 1. Result of algorithm calculating fuel consumption (per unit) (own study)**

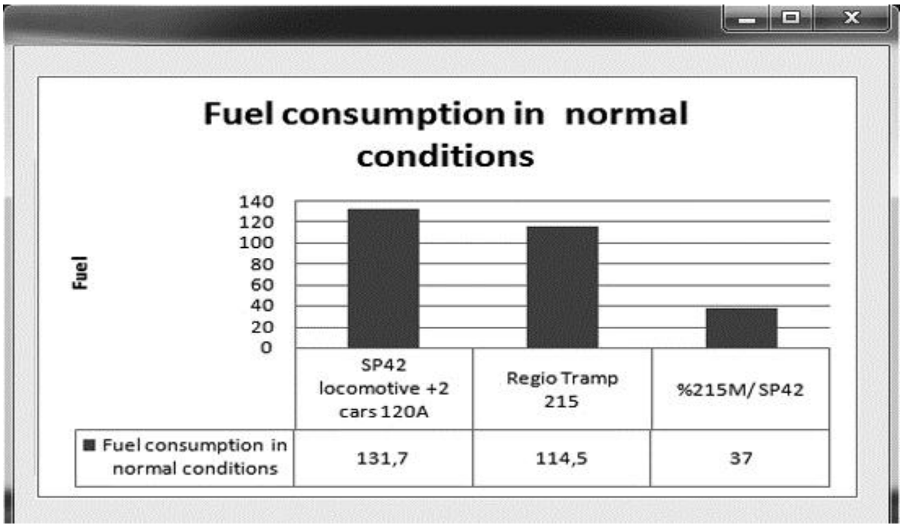


**Fig. 2. Result of algorithm calculating fuel consumption (normal) (own study)**

The first step comparison vehicles of computer algorithm are presented in fig. 1.:

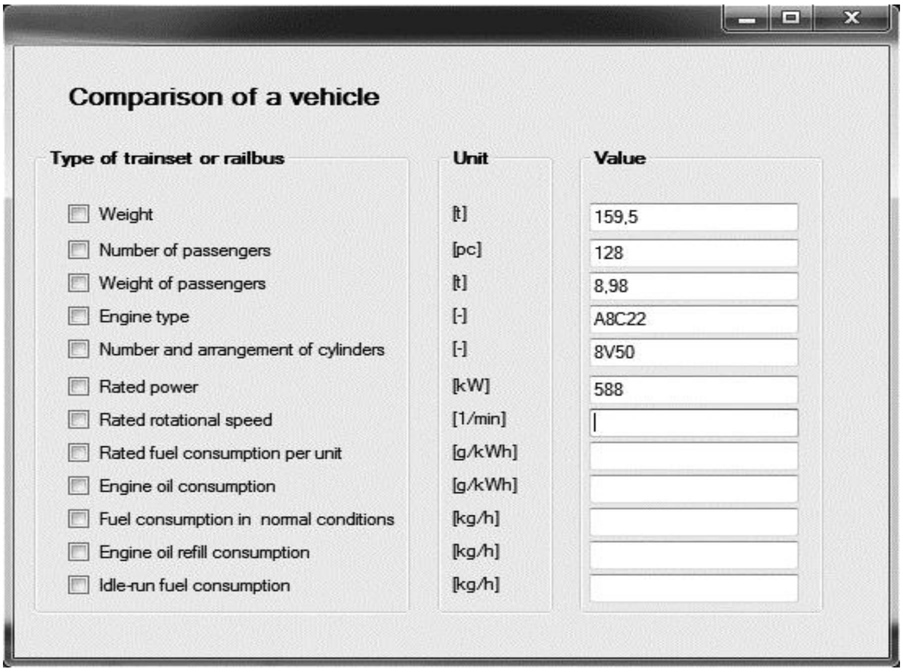


**Fig. 3. Comparison vehicles (own study)**

## 2. PROPERTIES OF RAILBUSES MANUFACTURED IN POLAND AND ABROAD

Railbuses are light traction vehicles manufactured by a number of companies worldwide (Gola, Montusiewicz & Świć, 2011; Świć, & Gola, 2013), including Siemens (the Netherlands), Adtranz (Germany), Bombardier/DWA (Germany), Wagonka Studenka (Czech Republic), Fujii Hi (Japan), Alstom (Germany), Goninan (Australia), DE Dietrich (France).

The parameters of railbuses manufactured by foreign companies are listed in Table 2.

Railbuses can develop a speed ranging from 90÷150 km/h, yet their operational speed is usually approx. 120 km/h.

Their engine power ranges from 200÷2x380 kW. The number of seats ranges from 36÷74. The maximum unit power of such bus is 12.9 kW/t.

These buses are powered by under-floor diesel engines manufactured by such companies as MAN Eurol, Volwo Euro I, MTn Euro I, MTN Eurol, Dentz, Man Euro II and Niigata DMF.

In Poland, railbuses are predominantly manufactured by three companies:

- ZNTK Poznań, the manufacturer of Regio-Tramp 213M and Regio Tramp 215M,
- KOLZAM Racibórz, the manufacturer of 208M and SPA-66/AS-66,
- ZNTK Bydgoszcz, the manufacturer of 214M.
- Table 3 gives the comparison of parameters of railbuses manufactured in Poland.

Regio Tramp 213M and 215M (Figs. 1 and 2) are light modern low-floor diesel railbuses for passenger service on normal-track lines.

These vehicles offer a broad spectrum of possibilities owing to their modular equipment which can be tailored to user requirements.

These vehicles can either consist of up to three units interconnected with a coupler and a bridge (e.g. 214M) or a single unit (e.g. 213M).

One of the most important features of these vehicles is that they can automatically change their wheel track from 1435 mm to 1520 mm.

These vehicles are relatively inexpensive and have low maintenance costs, which in fact increases the profitability of passenger service on the lines excluded from railway traffic by the PKP Polish Railways.

**Tab. 2. Technical data of railbuses manufactured by foreign companies (own study)**

| Manufacturer | Country of user | Year of construction | Track [mm] | Operational speed [km/h] | Power [kW] | Length [mm] | Number of seats /standing room | Power per weight [kW/t] | Notes |
|---|---|---|---|---|---|---|---|---|---|
| SIEMENS | Netherlands | 1980 | 1435 | 120 | 2x320 | 26170 | - | - | - |
| Adtranz | Germany | 1990 | 1435 | 129 | 2x257 | 25500 | 53/13 | 12.9 | Engine MAN Euro I |
| Bombardier/ DWA | Germany | 1990 | 1435 | 100 | 265 | 16540 | 53/13 | 11.5 | Engine Volvo Euro I |
| Wagonka Studencka | Czech Republic | 1990 | 1435 | 90 | 206 | 13250 | 36 | 11.1 | Engine Volvo Euro I |
| Fujii HI | Japan | 1990 | 1067 | 110 | 296 | 20000 | 3x35 | 8.5 | Engine Niigata DMF |
| Alstom | Germany | 1992 | 1435 | 120 | 315 | 27260 | 60/13 | 7.7 | Engine MTU Euro I |
| Goninan | Australia | 1994 | 1600 | 135 | 2x231 | 25900 | 50 | 9.2 | Engine Bentz |
| ABB | Australia | 1994 | 1435 | 150 | 3x380 | 3x25250 | 3x54 | 7.0 | Engine Commins |
| SIEMENS | Germany | 1995 | 1435 | 100 | 2x228 | 24800 | 74/ 100 | 11.12 | Engine Euro II |
| Alstom | Germany | 1999 | 1435 | 120 | 2x257 | 28900 | 63/17 | 10.5 | Engine MAN Euro II |
| De Dietrich | France | 2000 | 1435 | 140 | 2x257 | 28900 | 63/17 | 10.5 | Engine MAN Euro II |

**Tab. 3. Comparison of buses manufactured in Poland (own study)**

| **Type** | 207M + 207 Mr | 208 | SDA-66/AS-66 | 207Ma+207 Mra+207Mb | 213 | 214 M |
|---|---|---|---|---|---|---|
| **Manufacturer** | ZNTK Poznań | KOLZAM Racibórz | KOLZAM Racibórz | ZNTK Poznań | ZNTK Poznań | PESA Bydgoszcz |
| **Number of units** | 1÷2 | 2 | 1 | 3 | 1 | 1 |
| **Length with bumpers** | 30920 mm | 19200 mm | 16500 mm | 45940 mm | 17000 mm with automatic clutch | 18000 mm |
| **Unladen weight** | 54000 kg | 38800 kg | 23200 kg | 82000 kg | 27500 kg | 23520 kg |
| **Power** | 200 kW | 157 kW | 92/110 kW | 2x200 kW | 250 kW | 250 kW |
| **Type of gear** | hydraulic | hydro-mechanical | mechanical | hydraulic | hydro-kinetic | hydro-kinetic |
| **Maximum speed** | 90 km/h | 90 km/h | 90 km/h | 90 km/h | 120km/h | 110 km/h |
| **Seats** | 96 | 60 | 66 | 136 + 4 | 38 | 60 |
| **Standing room** | 140 | 68 | 74 | 196 | 52 | 70 |

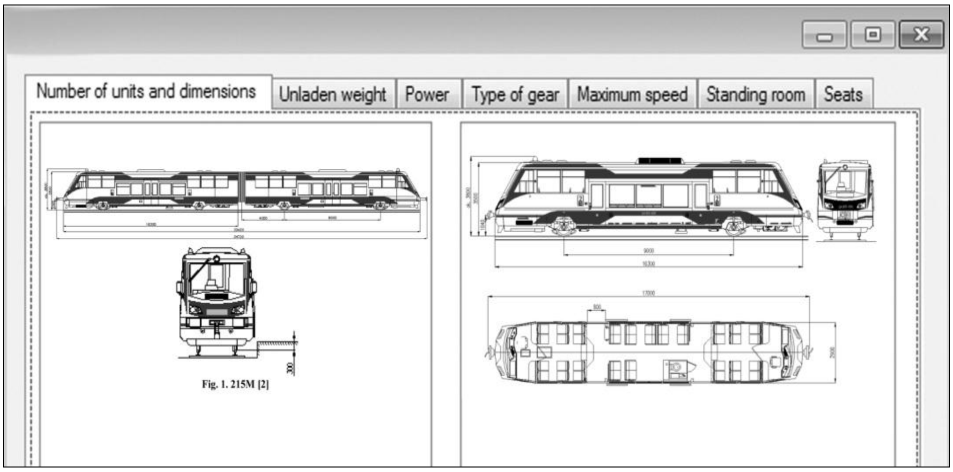


**Fig. 4. Computer algorithm to comparison of buses (own study)**

The main operational advantages of these vehicles include:
- reduced environment-polluting emissions due to the application of diesel engines which comply with the EURO2 standard (Lalik, 2008),
- reduced noise due to the application of shields and increased floor thickness, with particular emphasis on thermal and sound insulation,
- low axle-load of 140÷150 kN and thus a less destructive impact on rail tracks,
- relatively low energy consumption due to the application of light materials in vehicle design,
- reduced vehicle weight due to light steel design, the application of diesel engines with low fuel consumption and the use of heat from the engine and gear cooling system for vehicle heating,
- lower financial outlays on vehicle inspection and maintenance due to the application of maintenance-free subassemblies which wear to a little extent and do not require constant supervision,
- the use of environment-friendly materials, e.g. water-soluble painting materials,
- the use of recyclable materials, e.g. steel and parts made of plastics.

## 3. SELECTED PARAMETERS OF RAILBUSESUSED IN THE CALCULATION ALGORITHM

A selection of operational parameters of railbuses used in the calculation algorithm is illustrated using 208M as an example. According to the manufacturer's nomenclature (Basak & Biliński, 2007), 208M is a third-generation bus characterized by high comfort of travel (they are easy to get in and out of), modular design, low floor, on-board diagnostics, air-conditioned cars, and a closed WC system. Third-generation buses have a lower floor in the entire passenger space, while the floor height in the central part of the bus is 575÷600 mm (Basak & Biliński, 2007). The power units are mounted on an independent carrying frame, which considerably facilitates operation and maintenance processes. The buses are equipped with under-floor Power Pack integrated power units (Marciniak, 2009; Cisowski & Wojciechowski, (2011).

These buses are characterized by (Basak & Biliński, 2007):
- low purchase and operational costs, which leads to a higher profitability of passenger service on both local and regional lines,
- are adapted for getting in from both high and low platforms, i.e. from the level of a rail head (sliding doors),
- suitable for different levels of traffic due to their modular design and multiple travel,
- can be used for both cross-border and regional traffic on secondary lines as well as on lines which run in mountainous and sub-mountainous areas,

– high body inclination and small railway track arcs,
– are adapted to transport disabled passengers (getting in / getting out),
– separate space for the transport of  large luggage and bicycles,
– ergonomic chairs  with “vandal-resistant” design,
– ecological (closed) WC cabins adapted for disabled passengers,
– a modern hydro-mechanical under-floor drive system,
– a modern ecological combustion engine which complies with the EURO II standard,
– are equipped with an on-board computer which enables both drive system control and on-board diagnostics.

## 4. ANALYSIS OF ESTIMATED RUNNING COSTS OF A RAILBUS – RESULTS OF THE WORK CALCULATION ALGORITHM

The analysis of running costs involved calculating an estimated cost of transporting about 40 passengers at a distance $l$ = 100 km by an SP42 locomotive with one 134-type car and by a 207-type railbus.

All calculations were based on the generated results of the works calculation algorithm. The algorithm in the course of calculation takes into account:
– route recalculation,
– energy consumption,
– final conversion,
– fuel consumption,
– specific fuel consumption
– the cost of fuel,
– converting liters of fuel per 1 kg of fuel.

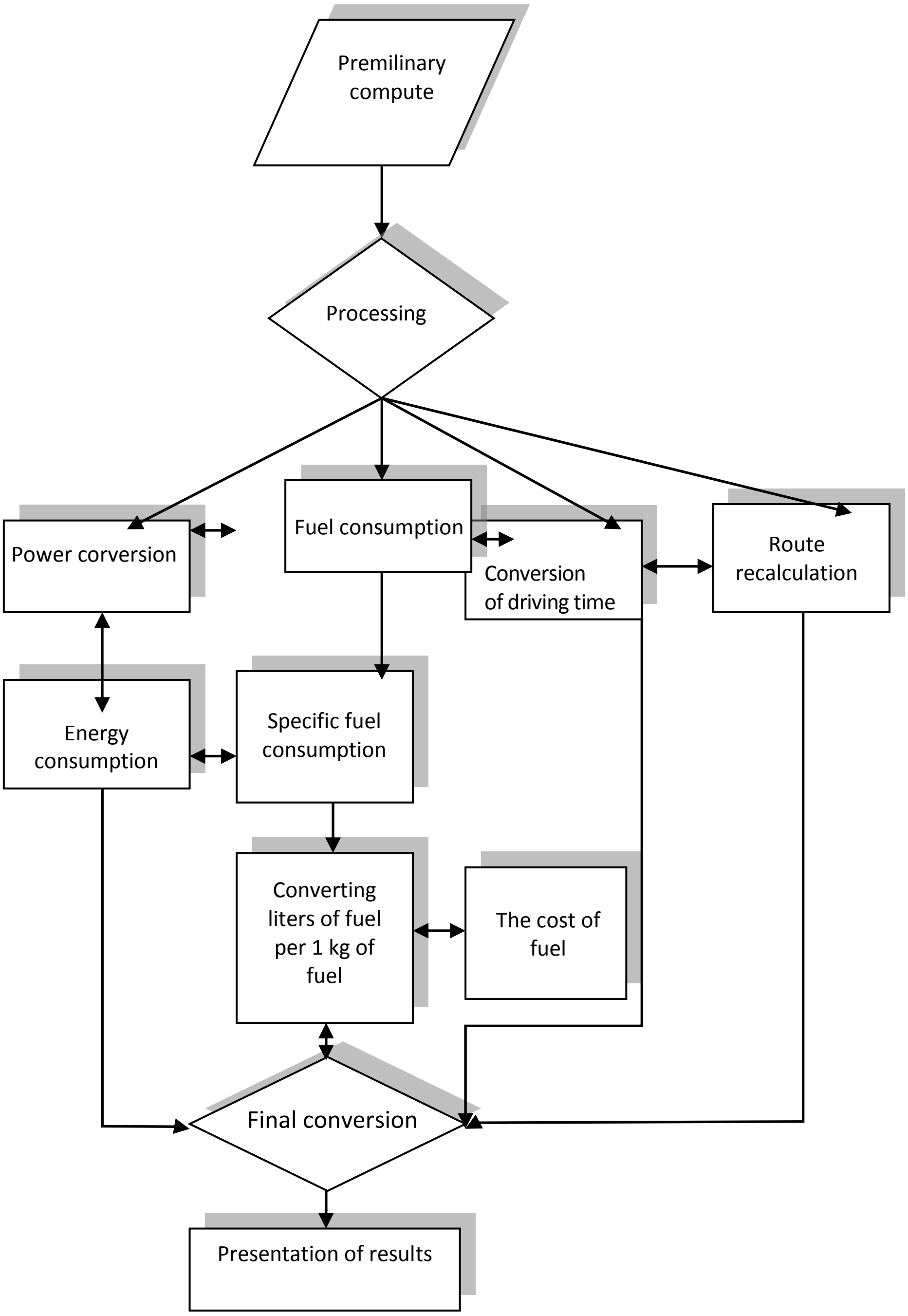


**Fig. 5. Graph computer algorithm steps (own study)**

Below are the steps in the process of computing the computer application:

**Stage 1. Calculate the cost of the operational cost of SP42 locomotive with one car:**
*Step 1.* Power of SP42 – P=588.2 kW (Stokłosa & Cisowski, 2008),
*Step 2.* Route – l = 100 km,
*Step 3.* Time of travel – t = 2 h,
*Step 4.* Unit fuel consumption – p = 224.4 [g/kWh],
*Step 5.* Energy consumption – E = 2·588.2 = 1176.4 kWh,
*Step 6.* Fuel consumption – P = 224.4·1176.4 = 263984.16 g ≈ 264 kg,
*Step 7.* Converting fuel into litres – 1 kg of fuel ≈ 1.3 litre,
P = 264·1.3 = 343.2 l,
*Step 8.* Cost of 1 liter diesel oil – 2.7 zloty,
*Step 9.* Fuel cost – Kp = 343.2 x 2.7 = 926.64 zloty.

**Stage 2. Calculate the cost of the operational cost of K1 locomotive:**
*Step 1.* It was assumed that the cost of one-day operation of this locomotive was 4000 zloty, which means that for 2 hours of operation:

$$K_1 = \frac{4000 \cdot 2}{24} = 333{,}5 \text{ zloty} \tag{1}$$

*Step 2.* A conductor was employed in the car for passenger service. An average monthly salary of the conductor was estimated at 2000 zloty per 200 hours a month.
The cost of conductor work for 2 hours (train travel):

$$K_2 = \frac{2000 \cdot 2}{200} = 20 \text{ zloty} \tag{2}$$

*Step 3.* It was assumed that the cost of one-day operation of a 134-type passenger car was 2000 zloty.
The operational cost of this car was:

$$K_3 = \frac{2000 \cdot 2}{24} = 166{,}66 \text{ zloty} \tag{3}$$

*Step 4.* K4 denotes the consumption of other operational materials K4 = 50 zloty (lubricating oil for wheel flanges, engine lubricant, sand, cooling water).

The total cost of 100 km travel (locomotive with one car):

$$K = \sum K_i = 926{,}64 + 333 + 20 + 166{,}66 + 50 + 1496{,}30 \text{ zloty} \tag{4}$$

**Stage 3. Calculate the cost of the operational cost of 207 railbus:**
*Step 1.* Engine power – P=200 kW,
*Step 2.* Route – l = 100 km,
*Step 3.* Time of travel – t = 2 h,
*Step 4.* Unit fuel consumption – p = 209 g/kWh,
*Step 5.* Energy consumption – E = 2·200 = 400 kWh,
*Step 6.* Fuel consumption – P = 209·400 = 83600 g = 83.6 kg,
*Step 7.* Converting fuel into litres:
P = 83.6 x 1.3 = 108.68 ≈ 109 l,
*Step 8.* Cost of fuel:
1 l engine oil costs 2.7 zl/l,
Kp = 109 x 2.7 = 294.3 zloty.

**Stage 4. Calculate the cost of the operational cost of a railbus:**
*Step 1.* It was assumed that the cost of one day of operation of a railbus was 1500 zloty, which means that for 2 hours of operation:

$$K_1 = \frac{1500 \cdot 2}{24} = 125 \text{zloty} \tag{5}$$

No conductor on the bus. Operational materials K4 = 25 zloty

*Step 2.* The total cost of 100 km travel (railbus):

$$K = \sum K_i = 294{,}3 + 125 + 25 = 444{,}30 \text{ zloty} \tag{6}$$

*Step 3.* A ratio between the locomotive and railbus costs:

$$k = 1496{,}30 / 444{,}30 = 3{,}96 \text{ zloty} \tag{7}$$

**Tab. 4. Comparison of costs of 100 km travel of a locomotive with one car and a railbus–results of the work calculation algorithm (own study)**

| Cost specifications | Diesel locomotive with one car | Railbus |
|---|---|---|
| Fuel consumption [zl] | 926.64 | 294.3 |
| Operational cost K1 [zl] locomotive/railbus | 333 | 125 |
| Conductor work cost K2 [zl] | 20 | - |
| Car use cost K3 [zl] | 166.66 | - |
| Cost of operational materials K4 [zl] | 50 | 25 |
| Total cost | 1496.30 | 444.3 |

Beloware presented results of cost specifications Diesel locomotive with one car and Railbus.

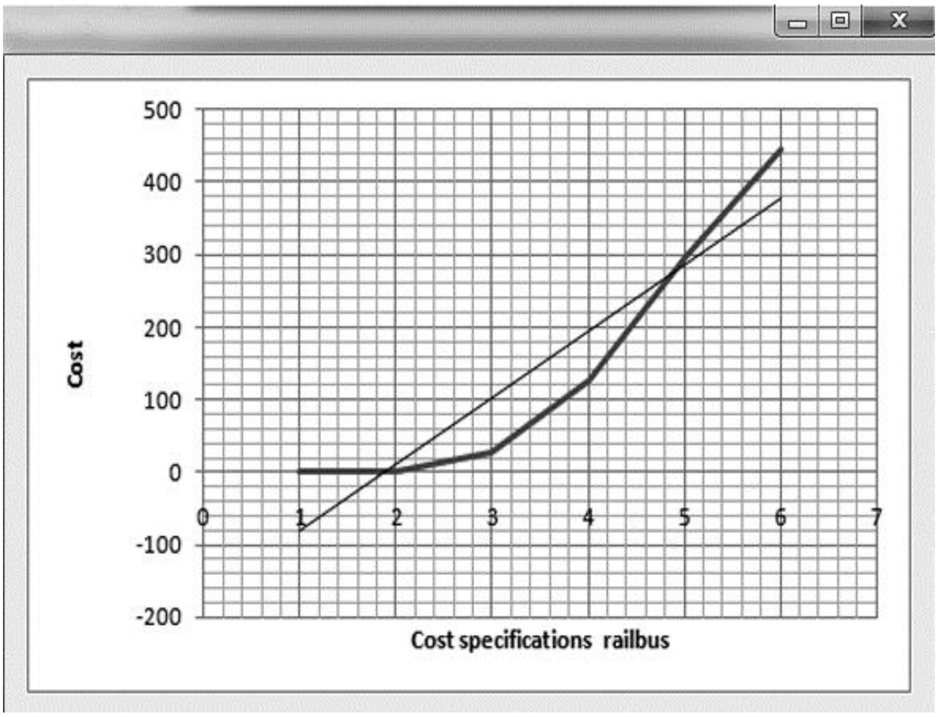


**Fig. 6. Calculation results of computer algorithm for Railbus (own study)**

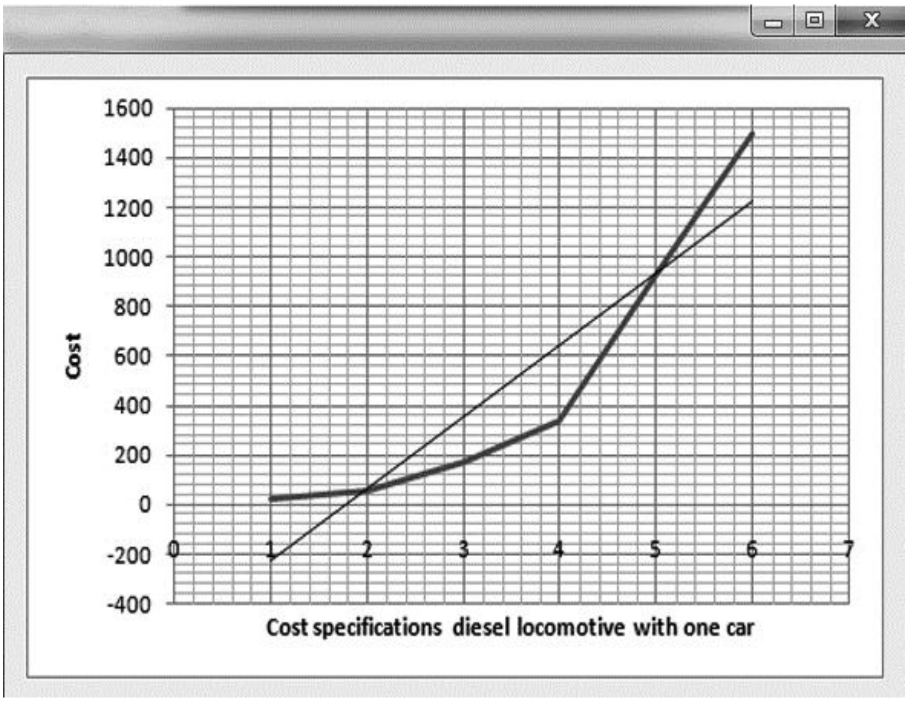


**Fig. 7. Calculation results of computer algorithm for Diesel locomotive with one car (own study)**

An algorithm analysis reveals that buses of this type can be used on lines which are in relatively low technical condition and have an axle load of 13÷14 t/axle. Their maximum speed is 90 km/h. The buses have seats for 60÷66 passengers, with standing room for 68 and 74. Railbus operating costs are lower more than 70% than diesel locomotive with one car.

## 3. CONCLUSIONS

Based on the analysis results, the following observations and conclusions have been drawn:

1. Computer algorithms for estimating operating costs are an effective tool to assist transportation process,
2. As a consequence, the maintenance of regional trains required and still requires considerable financial outlays,
3. Economic effectiveness of passenger railway services on secondary railway lines can be significantly increased if light rail vehicles are used instead of a diesel locomotive with two passenger cars.

4. P. 1 demand can be met if light railbuses, Regio Tramp 215M or 213M, are used.
5. 215M and 213M buses manufactured in Poland can compete with foreign products of a similar type.
6. 215M and 213M railbuses ensure high travel comfort, and they are easy and economic to operate.

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