Climate Change and Energy Consumption – Examples Associated with Railway Construction

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Summary
The practice of designing and constructing new railway lines should take into consideration certain global phenomena, whose significance will increase over time. One such phenomenon is the ongoing climate change. This is accompanied by a simultaneous depletion of non-renewable energy sources. The occurring changes may trigger cause-and-effect sequences, which means that an effect may become a cause of another change or further changes. The article offers some short examples of such sequences – both those originating from nature and those that can be initiated while considering the railway infrastructure that is yet to come into being.

Keywords: railway construction, climate and energy consumption, cause-and-effect sequences

1. Introduction

According to the currently available information, the land connections leading to the planned New Central Polish Airport (NCPA) will involve the construction of 1,300 km of new railway lines [7]. The range of modernisation works aimed at upgrading the existing lines in relation to the said project will also be considerable. One of the elements determining the effective operation of NCPA will also be railway connections. Even the best-quality landing areas, the latest navigation systems, and the most spacious and secure terminals are not enough when the passengers of the landing planes crowd on platforms, waiting for their delayed trains, and those about to depart do not make it on time to check in. To eliminate such anomalies, the constructed and modernised railway lines need to be highly reliable [3]. When it comes to railway routes, this requires the fulfilment of a number of conditions, with the most important of them being:

- coordinated and thoroughly analysed designs, based on a meticulous examination and survey of the subsurface conditions and buried utilities,
- experienced contracting teams with special-purpose machinery at their disposal,
- efficient supervision and insightful acceptance procedures of works at all stages, based on accurate and detailed measurements.

These conditions are not easy to meet and require a lot of thought and very good organisational preparation. Time pressure, coupled with limited design potential and construction resources, may lead to all efforts being concentrated on activities ending with the handing over of tracks, facilities, and equipment for use and operation, while passing over factors whose significance will surface later on. The article concerns several such factors taken into consideration in the practice of constructing contemporary railway infrastructure.

Forecasting the development of various social and economic phenomena and the course of changes occurring in the natural environment globally, it would be possible to notice many favourable and unfavourable symptoms affecting the role of the railway industry. It is difficult to determine the accuracy of such predictions. But there are two absolutely unquestionable factors that need to be taken into account when constructing new railway lines. These are climate change and the depleting sources of non-renewable energy. Arguments claiming that it is difficult to take these factors into consideration because they are not included in standards are countered with an argument that designers perform creative work [5] and, therefore, no standards exempt the constructors of new railway lines from visualising the conditions in which these lines will be used in a few dozen years.

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2. Selected cause-and-effect relationships in the expected changes

The consequences of climate change and gradual depletion of non-renewable energy sources may have a different scope and degree of impact on railway infrastructure. Figure 1 shows a couple of factors that form cause-and-effect sequences. The figure includes only a fragment of certain phenomena, not a full systematised view thereof. A broader description of threats stemming from climate change can be found in one monograph [2] and in many papers and reports, e.g. [4].

In a cause-and-effect relationship, a cause leads to some effect, and this effect becomes the cause of another effect, and the cycle can go on repeatedly. The relationship between a cause and its effect should be based, according to David Hume, a well-known English philosopher (1711–1766), on experience and should not be determined a priori. Many observations and a range of evidence can prove the causality presented in Figure 1.

2.1. Selected effects of climate change

Transport is one of the most vulnerable domains of our domestic economy to climate change. The effects of the increasingly warmer atmosphere and the growing temperature levels include a greater risk of track buckling. This effect will in turn require considerable improvements in track superstructure diagnostics. The need to improve the methods of measurement of neutral temperature levels is becoming especially urgent. The Railway Institute can offer an appropriate concept in this domain.

A cause-and-effect sequence involving the risks of track buckling could be extended by analysing the options available in the area of the technology and procedures adopted for repairs of track superstructure in a shortened work season (outside excessive heat hours), diagnostic training, etc.

The second example of the consequences of climate change is the increased frequency of forest fires. In this case, one should take into account three reasons that became apparent in the tragic forest fire that took place in the US in 2018. These are: high temperatures, a long period of drought, and strong winds. The potential of railway units to counteract such disasters is limited, but well-organised monitoring of forest buffer strips using drones, which could – to some extent – monitor instances of wind fallen trees found within the gauge and the condition of dewatering equipment after storms, is certainly worth a more in-depth analysis.

When designing new railway lines, it is important to bear in mind the phenomena already noted in Poland, when torrential downpours flooded roads under land-bridges, leaving cars submerged. On one of the

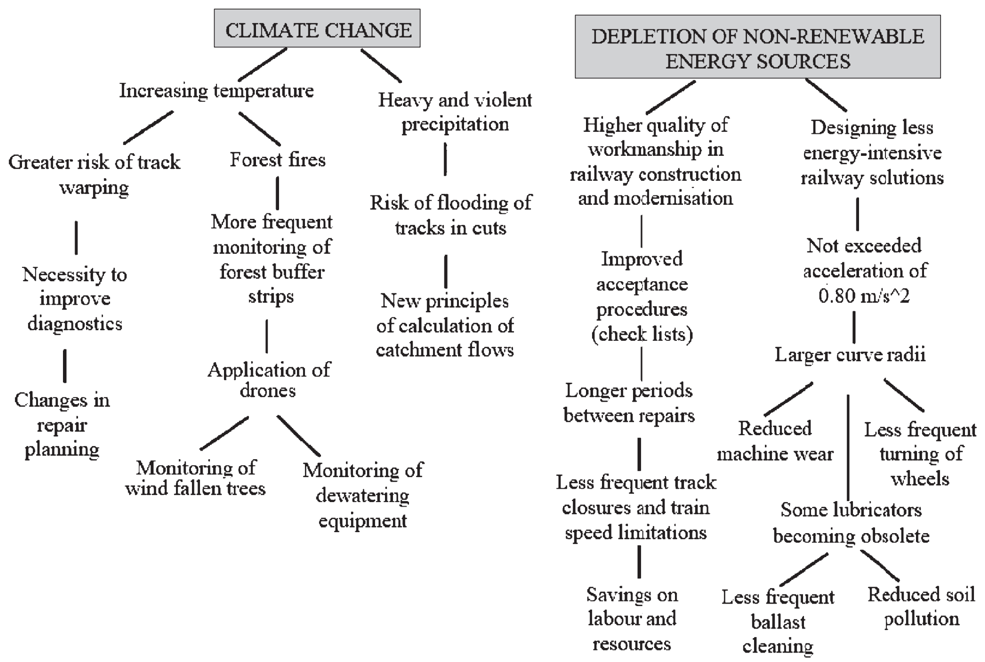

Fig. 1. Fragments of cause-and-effect sequences (chains) [The autor's own elaboration]

[2] To some extent, it was because of ditches being clogged.

railway lines, flooded the road below a railway bridge up to its supporting structure. On many sections of the line, water reached the level of the rail head[2]. These events call for a critical review of the methods used to estimate catchment flows for the purpose of designing new routes, which should be carried out in collaboration with the Institute of Meteorology and Water Management.

2.2. Consumption of non-renewable energy

Issues related to energy in railway transportation are among the main problems dealt with by the International Union of Railways (UIC) [6]. Dozens of factors determine the amounts of consumed energy [8]. Many of them also underlie the life-cycles of railway routes, i.e. their planning, design, construction, use and operation. Discussing all of them would require a separate extensive publication. Two details presented in Figure 1 in the form of short cause-and-effect sequences are just an example of how broad the area of potential savings on energy is.

The level of energy consumption in the use and operation of railway routes will decrease if the quality of works performed in the construction and modernisation of railway lines is sufficiently high. The author has provided many examples proving that this quality is often poor, with recent examples described in one monograph [2]. An obligatory condition for improving the quality of workmanship should involve a principle that new railway lines are constructed in a way that the value of the synthetic indicator of the track superstructure quality at the time of final acceptance is $J \leq 1.0$ mm. Reaching such a quality of workmanship means that it would not be necessary to proceed with handling instances of track deformation soon after a new line is handed over for use and operation. There are cases of railway lines abroad [2] where the value of J has amounted to 0.5 mm, which guarantees a longer time between failures, rarer track closures and train speed limitations, which translates into savings on energy and resources.

The impact of the condition of track superstructure, described by the value of J, on the frequency of repairs can be illustrated with a comparison of two track sections, as shown in Figure 2. The left-hand section of the track is in bad condition, and the right-hand section, i.e. starting at about km 37, is in good condition. Both of the presented sections illustrate an increase in the value of J at an interval of approx. 1.5 year. In the case of the left-hand section, the increase amounted to 1–2 mm, and in the case of the right-hand section – with one exception – it was within the range of 0.1÷0.2 mm.

Among the conditions guaranteeing the expected quality is the necessity to carry out thorough acceptance procedures for all works – from partial acceptance of hidden (temporary) works to final acceptance. The large impact of acceptance procedures on the possibility to demand the right quality of works legitimises the discussion of an acceptance case that should not have taken place. This was the final acceptance of a several-kilometre track section after modernisation. The committee was provided with measurements in the form of tables and graphs. Table 1 includes a fragment of synthetic evaluation activities performed on six 100-metre-long track sections. The synthetic indicator of track quality ranges from 0.2 to 0.6 mm, which proves that the quality of the performed works is exceptionally high for PKP. Looking at further columns in the table raises significant doubts: they offer zero values of standard deviation for vertical irregularities ('vertical') and near-zero (0.1 mm) values of standard deviation for horizontal irregularities ('horizontal').

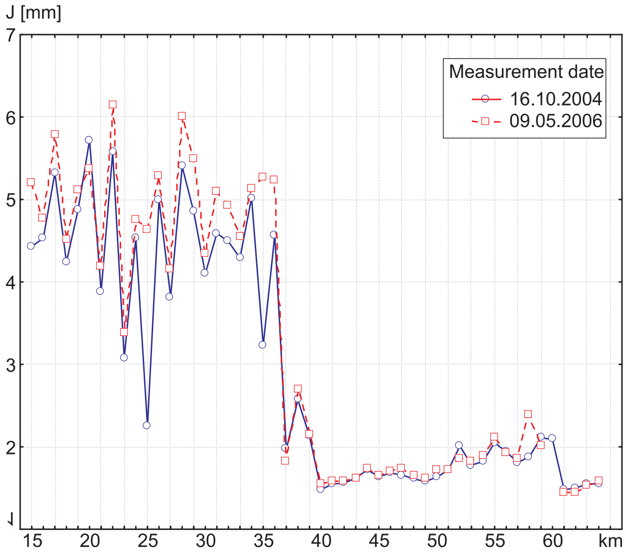

Fig. 2. Increase in the value of the track quality indicator [by Maria Bałuch]

It would be reasonable to repeat that the synthetic indicator of track quality is a function of standard deviation of four geometric quantities

$$J = \frac{S_z + S_y + S_w + 0{,}5S_e}{3{,}5}, \tag{1}$$

where: S_z, S_y, S_w, S_e – standard deviation of respectively – vertical irregularities, horizontal irregularities, twist and gauge.

The zero or near-zero values of S_z and S_y invalidate the printed result for J. The reason behind the incorrect values appears to be clear after looking into

Table 1

Synthetic track evaluation calculated for sections of 100 [m]

Limit value of J: 2.0

Section		STANDARD DEVIATION							IRREGULARITIES						
		J	Gauge	Gra-dient	Superel-evation	Twist	Ver-tical	Hori-zontal	Gauge	Gra-dient	Superel-evation	Twist	Ver-tical	Hori-zontal	W5
.5000	.4000	0.4	0.5	0.3	1.1	1.2	0.0	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.4000	.3000	0.6	0.6	0.4	1.3	1.7	0.0	0.1	0.00	0.03	0.00	0.03	0.00	0.00	0.03
.3000	.2000	0.6	0.5	0.3	0.8	1.6	0.0	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.2000	.1000	0.4	0.7	0.4	0.5	0.8	0.0	0.1	0.00	0.02	0.00	0.00	0.00	0.00	0.00
.1000	.0000	0.2	0.5	0.3	0.4	0.5	0.0	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
.0000	.9510	0.3	0.6	0.3	0.4	0.5	0.0	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[The author's own elaboration on the basis of track condition measurements].

a fragment of measurements printed at 1-metre distances (Table 2). The values of track super-elevation amounting to approx. 80 mm mean that the inspected section is a curve. In such a case, the versed sine ('horizontal') should have values evidently different than zero. These two fragments of measurements listed in Tables 1 and 2 clearly show that the measurements on the basis of which works were accepted lacked two essential parameters, i.e. horizontal and vertical irregularities. This is additionally proven by graphs, where a simple graph of versed sines is found below a trapezoidal graph of super-elevation[3].

Given the restrictions on the volume of the article, a description of the conducted analysis of the causes of the said situation has been left out, but it is reasonable to suggest carrying out acceptance activities in a manner that would eliminate similar mistakes. This should be possible if there are acceptance procedures of particular work categories – based on check lists – in place and applied to different specialities[4]. In the case in question, appropriate check lists would serve three purposes:

1) to determine the right sequence of tasks making up the entirety of the acceptance procedure,
2) to prevent individual components of acceptance documents from being omitted,
3) to engage committee members specialising in non-technical disciplines (lawyers, economists) in the whole process of the acceptance procedure.

Applying check lists in the acceptance procedure of hidden works would translate into improved effectiveness of repairs, i.e. the other component of the quality of works, next to accuracy [3]. Check lists should be developed on the basis of experience gained from different cases of acceptance-related activity, and drawn up by people with not only theoretical knowledge but also their own observations made in practice.

2.3. Taking energy consumption into account in design-related considerations

The amounts of energy consumed by the designed and constructed railway lines will depend on dozens of parameters defining all railway-related specialities. It would take a few dozen publications to calculate them all, considering the construction of rolling stock, networks and power supply solutions, automation, superstructure and substructure, etc. Only one parameter has been adopted as an example of cause-and-effect sequences encompassing energy consumption; a parameter on which the track geometry depends, i.e. the uncompensated lateral acceleration.

When constructing new railway lines and modernising the existing ones, it is necessary to abide by the principle that the geometry of tracks should not be changed for at least several dozen years, and it is best to assume that the adopted geometry should last and perform as necessary for 100 years. Taking the above into account, the author suggests adopting a principle that the value of acceleration on the designed railway lines should not exceed 0.8 m/s^2. This would result in larger radii of curves. This would, in turn, translate into reduced wear of tracks, less frequent turning of train wheels, and an option to resign from some lubricators. Resignation from lubricating tracks would mean longer periods between ballast cleaning, avoiding soil pollution and disposing of lubricant-covered

[3] It was decided not to include these graphs, assuming that tables are sufficient proof of the lack of measurements.

[4] Concepts of a new variant of such lists, so-called check-warning lists, are provided in the monograph [2] and publication [3].

Table 2

A fragment of measurements at distances of 1 mm

KILOMETRE [km]		GAUGE [mm]	GRADIENT [mm]	SUPERELEVATION [mm]	TWIST [mm]	VERTICAL [mm]	HORIZONTAL [mm]
	,6960	0.6	0.5	75.2	–2.8	0.0	0.0
	,6950	0.2	0.4	75.7	–2.7	0.0	0.0
	,6940	–0.1	0.4	76.3	–2.5	0.0	–0.1
	,6930	–0.3	0.2	76.8	–2.3	0.0	0.0
	,6920	–0.1	–0.2	77.2	–2.1	0.0	–0.1
	,6910	0.3	–0.4	77.5	–1.7	–0.1	–0.1
	,6900	0.3	0.0	77.8	–1.3	0.0	–0.1
	,6890	0.0	0.4	77.9	–1.2	0.0	–0.1
	,6880	–0.2	0.2	78.1	–1.4	0.0	0.0
	,6870	0.0	–0.1	78.4	–1.6	0.0	0.0
	,6860	0.4	–0.4	78.9	–1.9	0.0	–0.2
	,6850	0.4	0.0	79.4	–2.2	0.0	0.0
	,6840	0.2	0.2	79.8	–2.5	0.0	0.0
	,6830	0.2	0.0	80.3	–2.5	0.0	–0.1
	,6820	0.2	0.0	80.9	–2.4	0.0	–0.1
	,6810	0.2	0.0	81.4	–2.3	0.0	–0.1
	,6800	0.2	0.1	81.8	–2.1	0.0	–0.1
	,6790	0.1	0.1	82.1	–1.7	0.0	–0.1
	,6780	–0.2	0.3	82.4	–1.5	0.0	0.0
	,6770	0.0	–0.2	82.6	–1.4	0.0	0.0
	,6760	0.7	–0.7	82.8	–1.5	0.0	–0.2
	,6750	0.8	–0.1	83.2	–1.8	0.0	0.0
	,6740	1.0	–0.2	83.7	–2.1	0.0	–0.1
	,6730	1.1	–0.1	84.2	–2.3	0.0	–0.1
	,6720	0.8	0.2	84.7	–2.4	0.0	0.0
	,6710	0.2	0.6	85.1	–2.4	0.0	0.0
	,6700	0.3	0.0	85.6	–2.3	0.0	–0.1
	,6690	0.4	–0.1	86.1	–2.2	0.0	–0.1
	,6680	0.3	0.1	86.5	–2.3	0.0	0.0
	,6670	0.3	0.0	86.9	–2.4	0.0	–0.1
	,6660	0.2	0.1	87.4	–2.3	0.0	0.0
	,6650	–0.1	0.2	87.9	–2.2	0.0	–0.1
	,6640	0.0	–0.1	88.4	–2.1	0.0	0.0
	,6630	0.0	0.0	88.7	–2.0	0.0	–0.1
	,6620	0.1	–0.1	89.1	–1.9	0.0	0.0
	,6610	0.6	–0.5	89.4	–1.8	0.0	–0.2
	,6600	0.9	–0.2	89.8	–1.7	0.0	0.0

[The author's own elaboration on the basis of track condition measurements].

crushed stone ballast. In some cases, reducing the curve radii would translate into a lower resistance to forward motion and lower noise.

3. Conclusions

The expected large scale of projects involving the construction of new railway lines in Poland creates an opportunity to perform the planned works in a way that, after a few dozen years, the generations to come will speak of their effects as highly as of the inter-war city of Gdynia and the Central Industrial District after half a century of their beginnings.

The construction of new railway lines should benefit from scientific support. There is a broad area of issues where Polish scientists and engineers can become instrumental in achieving the goals set by the decision-makers or, as argued by R.L. Ackoff (1919-2009) [1], in helping the decision-makers formulate these goals. When setting ambitious goals, it is reasonable to think about their significance in a few dozen years.

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