Retrofitting measure vs. replacement – LCA study for a railway bridge

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Abstract

The LCA study analyses a short-term retrofitting measure carried out for a railway bridge of the railway line Bamberg-Rottendorf (Germany). The retrofitting extends the lifetime of the bridge for further 15 years. Without this service life extension, the bridge would have been closed within half a year. The retrofitting site works were completed within 4 weeks without an impact on rail traffic. The measure increases the flexural strength of the bridge structure by screwed steel plates, which act as tension elements ("external reinforcement").

The LCA results for the retrofitting are compared to results of a total replacement of the bridge structure. The duration of planning and construction processes for a new bridge was estimated to be 2 years in total, what would have caused a closure of the rail track for 1½ years. Therefore, for the LCA of the bridge replacement a detour of 50 km over the whole closure period is considered in addition to construction related processes. The new bridge construction was defined to be a double-webbed T-beam carried out as a prestressed concrete structure.

The analysis period of the LCA study was set to 15 years including the new construction of the bridge after the retrofitting measure becomes ineffective. For both the retrofitting measure and the replacement of the bridge, no influential maintenance processes are required over the analysis period.

The results of the analysis show the great influence of the route closure and the associated detour. Already one day of route closure causes about twice the amount of environmental impacts as the entire retrofitting measure. Taking into account the whole closure period shows a marginal influence of all construction related processes and underlines the environmental relevance of transport distance extensions. This study furthermore demonstrates the environmental influence of route-shortening infrastructure such as bridges and tunnels and their reliability.

Keywords:

Life Cycle Assessment; Railway bridge; Retrofitting measure; Replace; Route closure

1 INTRODUCTION

This study analyses a short-term retrofitting measure carried out for a bridge on the railway line Bamberg-Rottendorf (Germany) by applying the Life Cycle Assessment (LCA) methodology. The results are compared to the environmental impacts caused by a complete replacement of the bridge construction.

The existing bridge structure was built in 1968 as a skew two-span girder. The prestressed concrete construction has a total span of 35 m (2 x 17,5 m). The two separated beams of the superstructure of the bridge were carried out as single-cell box girder.

The prestressing steel applied for the existing structures has a high tendency to stress corrosion. Therefore, the individual prestressing tendons can crack gradually without recognizing these cracks from outside. In combination with the little amount of reinforcing steel this causes the risk of a sudden failure without visible crack formation.

Based on this improbable, but possible scenario, the Federal Railway Authority would have closed the bridge and thus the railway line Bamberg-Rottendorf at the beginning of 2015 for the time span of the replacement. This would have caused a detour of 50 km for all trains over an alternative route for one and a half years.

The retrofitting measure was completed within four weeks and did not cause a closure of the railway route. Furthermore, the traffic flow on the crossing highway A70 was guaranteed by shifting the single lanes according to the construction progress of the retrofitting measure. The retrofitting extends the lifetime of the bridge for further 15 years. After these 15 years the bridge needs to be replaced, what can be prepared with an appropriate period of time and without any closure of the railway route.

2 LIFE CYCLE ASSESSMENT

The life cycle assessment (LCA) methodology is applied to determine environmental aspects and potential environmental impacts occurring throughout the life cycle of a product or service. A complete LCA according to ISO 14040 [6] and ISO 14044 [7] contains the following elements:

- Goal and scope definition
- Life cycle inventory
- Life cycle impact assessment
- Evaluation

2.1 Goal and scope

The goal of the LCA study is to compare the environmental impacts of the bridge retrofitting, which was carried out in four weeks and did not cause a closure of the railway line, with the replacement construction of the bridge with the consequence of a closure of the railway line for one and a half years.

According to engineer experience the planning, awarding and construction of a new bridge structure would have taken two years in total. However, it can be assumed that the planning would have started at the same time as the bridge retrofitting (Start 2nd half of 2014), i.e. the period for the line closure can be set to one and a half years (approx. 550 days). Therefore, the assessed scope and the system boundaries of both variants analysed can be defined as shown in *Figure 1*.

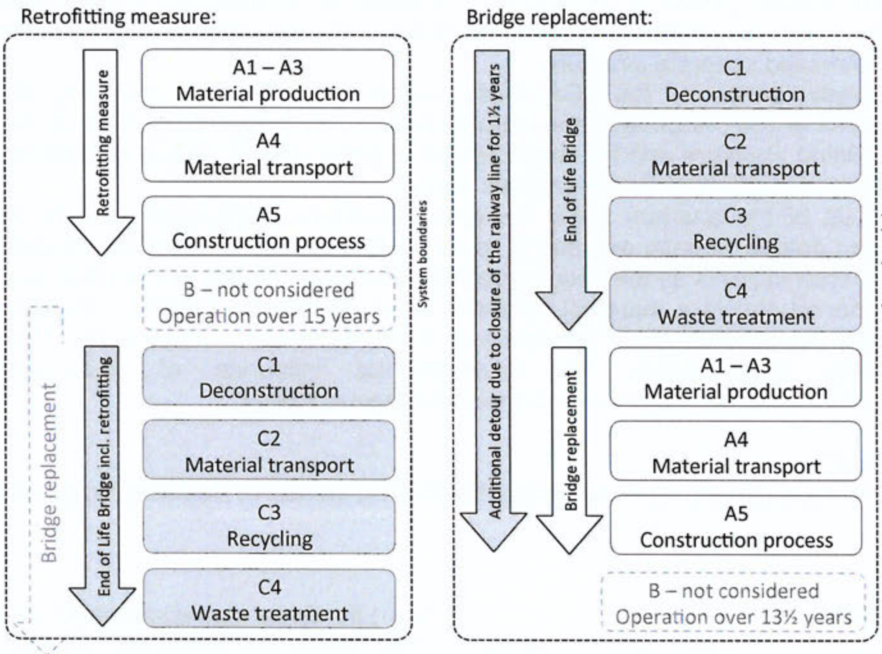

Figure 1: Scope and system boundaries of the LCA study

The denomination of the individual life cycle phases in *Figure 1* (A1-A3, A4, ...) is in accordance with standards of CEN TC350 (Sustainable Buildings and Civil Engineering Works).

The analysis period was set to 15 years and corresponds to the lifetime of the bridge structure after the retrofitting measure.

For both variants no influential maintenance measures are expected during the analysis period. Therefore, the operation phase (including maintenance, cleaning, etc.) is not considered in the LCA study, because it is identical for both variants.

Only the additional detour (50 km extra) caused by the usage of the alternative route will be considered for the replacement variant during the closure period.

In order to keep the construction phase for the bridge replacement after the end of life of the retrofitted structure as short as possible, the construction of the new bridge structure will be started before the deconstruction of the existing structures to be able to just "slide in" the finished new structure.

2.2 Life cycle inventory

During the life cycle inventory phase of the LCA all material and energy flows (inputs and outputs) necessary for the specific processes of the analysed life cycle phases are collected [6].

The materials (A1-A3) required for the bridge retrofitting are based on the shop drawings of the measure. The materials for the bridge replacement were estimated based on engineering experience.

For the bridge replacement only the replacement of the superstructure (without abutments and piers) is taken into account. The transport (A4) of the materials for the retrofitting was carried out by a lorry over a distance of 140 km. The concrete for the new construction is transported by a concrete mixing lorry from a nearby concrete mixing plant (10 km). Reinforcing and prestressing steel for the new structure will also be transported by lorry over a distance of 140 km. Based on experiences made throughout previous LCA studies it is known that construction processes (A5) generally have minor impact on the LCA results (compared to material production processes) due to low energy and material requirements. In order to reduce the effort for data collection, the construction processes are considered with 2% of the ecological impacts of material production processes [8]. Also the impact for deconstruction processes (C1) is set to 2% of the environmental impacts of material production processes.

Regarding the recyclability of the deconstructed materials it was assumed that 90% of the materials are introduced to recycling processes (C3) and that 10% are delivered to a landfill for inert material (C4).

The transport of deconstructed materials (C2) to recycling plants and inert material landfills is for both variants assumed to be similar to the material transports to the building site.

During the closure of the railway line Bamberg-Rottendorf all trains will be rerouted via Fürth, what causes a detour of 50 km [9]. In order to include necessary extra processes (i.e. shunting processes, waiting time, etc.) the detour was extended by 10%, what brings a total detour of 55 km.

The passenger transport on the Rottendorf-Bamberg line is performed by 34 daily train runs (17 in each direction). The passenger trains consist of four railway coaches and have a maximum capacity of 250 passengers. For this study it was assumed that all passenger trains have an average utilisation ratio of 75%, what results in 188 passengers per train.

Regarding freight transport the Umweltbundesamt (Federal Environment Agency) numbers 25 train runs per day on the Bamberg-Rottendorf line [10]. The average transport load of the freight trains was set to be 1000 tons.

The closure lasts for one and a half years, i.e. approximately 550 days.

2.3 Life cycle impact assessment

The life cycle impact assessment part of the LCA study determines the environmental impacts occurring over the product's life cycle [6]. Due to the limited extent of the paper, only three impact indicators are applied to express the induced environmental impacts (in the overall study a variety of indicators was utilized):

- Global Warming Potential (GWP)
  [kg CO2 eqiv.]
- Acidification Potential (AP)
  [kg SO2 eqiv.]
- Non-renewable cumulative energy demand (NR-CED)
  [kg MJ eqiv.]

The life cycle assessment was performed with the LCA-program SimaPro and the LCA-database ecoinvent v2.2 [11].

Before the influence of the closure is taken into account the results for the retrofitting measure and the bridge replacement are compared over the analysis period of 15 years (*Figure 2* to *5*).

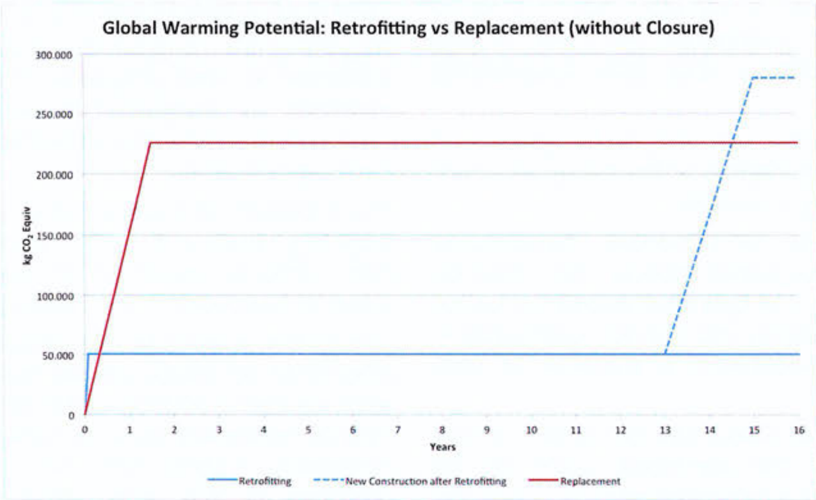

Figure 2: Retrofitting vs. replacement – GWP

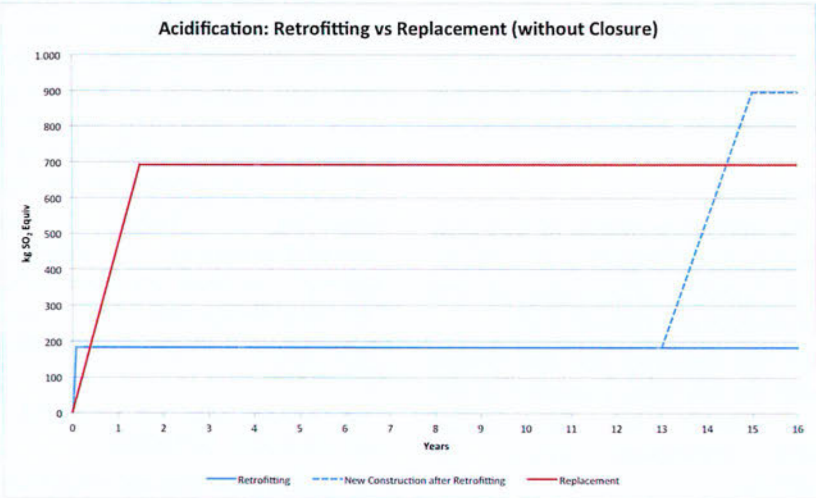

Figure 3: Retrofitting vs. replacement – AP

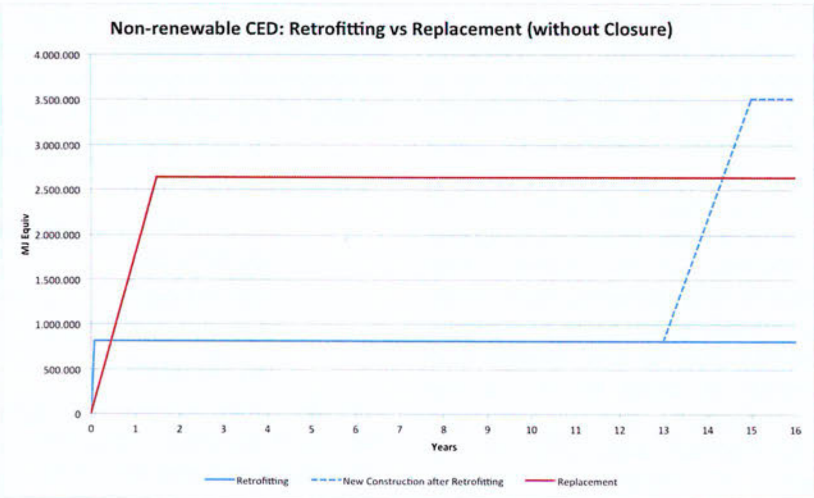

Figure 4: Retrofitting vs. replacement – NR-CED

The results for all three indicators show that the retrofitting measure causes lower environmental impacts than the replacement of the bridge. The retrofitting measure extends the lifetime of the bridge for 15 years, what postpones the environmental impacts for a new bridge structure.

Taking a look at the influence of the closure of the railway line demonstrates the main advantage of the retrofitting measure. In order to show the importance of the closure, the environmental impacts for a "one-day closure" will be compared to the results of the retrofitting measure and the bridge replacement (*Figure 5*).

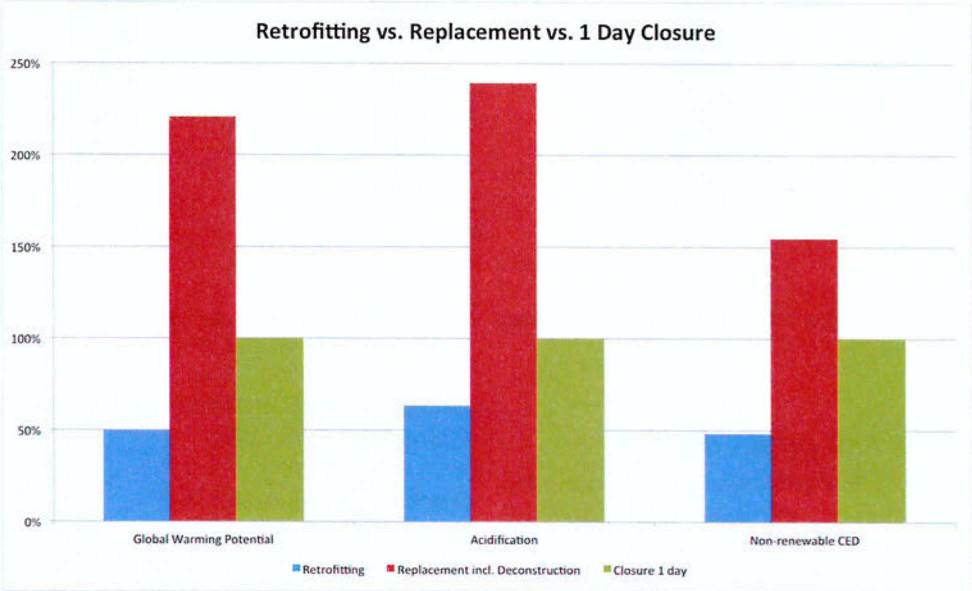

Figure 5: One-day closure vs. retrofitting and replacement

Figure 5 shows that the extra consumption of electricity for a closure of one day causes on average twice the environmental impacts as the complete retrofitting measure.

The bridge replacement causes 1.5- to 2.4-times higher environmental impacts than the one-day closure, which would be compensated after at least three days of closure.

Comparing the environmental impacts of the retrofitting measure and bridge replacement to results of the entire closure of the railway line over one and a half years demonstrates the marginal influence of construction processes in comparison to the influence of detours and extra distances for the railway traffic (*Figure 6*).

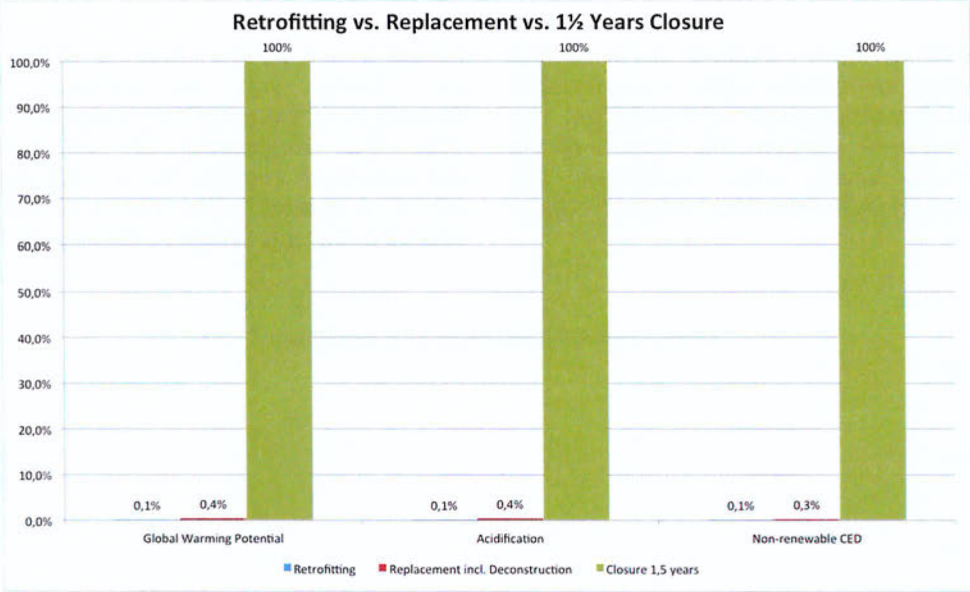

Figure 6: Closure for 1 ½ years vs. retrofitting and replacement

3 DISCUSSION AND CONCLUSIONS

This study shows the enormous environmental influence of transport services and transport distance extensions. The performance of the retrofitting measure for the analysed bridge indicates that avoiding a route closure is of higher environmental importance as the choice of construction methods and materials.

Thus, the study also underlines the environmental importance of distance-shortening engineering structures such as bridges and tunnels. The results of this study correspond with similar studies, which have shown the environmental influence of strategically important transport infrastructure assets. Hence, this study is one more example that demonstrates the importance of the availability and reliability of infrastructure systems.

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