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A proposal for cost-related and market-oriented train running charges

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1. Introduction

Track maintenance and renewal costs arise from wear and tear from train traffic and the context in which the track is placed. As a rule, maintenance operations are defined as small-scale operations (e.g. ballast compacting, track levelling and alignment, and rail grinding) that have a short life cycle. The purpose of the operations is to ensure a certain level of quality, reliability and safety. Thus, the useful life of maintenance operations depends on a series of factors (traffic, context, the quality of track elements, etc.) and diminishes as traffic increases. In general, the interval between two maintenance operations would be one to six years. Therefore, maintenance costs tend to be considered as short-term incremental costs.

Prolonged exposure to adverse conditions (e.g. rain, frost and rust) and, above all, wear and tear and deformations of track parts (e.g. rails, fastenings, sleepers and ballast) caused by traffic require more frequent maintenance operations. On the other hand, the cost of each maintenance operation tends to be higher than the previous one, since the pace of a track's wear and tear increases with the accumulated amount of traffic it has supported. The result is a gradual increase in maintenance costs.

Railway track elements need to be changed more occasionally [25 years could be considered their average life cycle according to Baumgartner (2001)] to prevent an

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uncontrolled increase in maintenance costs. This is what is known as renewal. Renewal costs refer to the replacement of such elements so the track's performance will remain the same as in the past (normally, when it was new or at the time of the last renewal). Therefore, renewals are much less frequent than ordinary maintenance operations; they cost more and their life cycle is longer. These features are associated more with long-term incremental costs.

According to the above, because train traffic gives rise to maintenance and renewal costs, the cost generated by running an additional train would be defined as an incremental cost (short-term for maintenance costs and long-term for renewal costs).

This direct relationship with traffic and the European Commission's Directive 2001/14/EC support for the recovery of incremental costs generated by train traffic are the reason why, in practice, all current European charging systems include maintenance costs. Very few charging systems expressly indicate that they are including renewal costs. One exception is the UK, which has a variable track usage charge that recovers renewal costs (Network Rail 2006). The decision of whether or not to include renewal costs in a country's charging system may be due to the magnitude of the sums involved – according to the International Union of Railways (UIC), renewal costs can easily double maintenance costs (UIC 2008) – or to their longer life cycle, which makes it more complicated to impose a levy for renewal costs on railway undertakings in the short term.

The train running charges developed in this article include maintenance costs as well as renewal costs, and help to overcome the difficulties arising from the gap between the magnitude of the cost involved in maintenance and renewal operations and their useful life.

2. Cost data as the basis for train running charges

Detailed studies have been carried out in some European countries to estimate the incremental costs of maintenance and renewal. In Finland, Austria, Sweden and Switzerland, the incremental costs were obtained by estimating a cost function and then proceeding to derive it with respect to tonnes-km (top-down approach). In the UK, a bottom-up method was used, starting with an analysis of the variations in cost caused by speed, axle load and unsprung mass per vehicle factors (Thomas 2002).

Apart from the above methods, which require a complete database and costly studies, the simplest way to estimate a rail network's maintenance and renewal costs should be to start with the infrastructure manager's annual accounts. The data could be used to estimate the incremental costs, considering that, according to the above-mentioned studies, they amount to around 10–30% of the average maintenance and renewal costs. Actually, however, a series of deficiencies in the infrastructure manager's accounting methods tend to make them difficult to quantify (Calvo et al. 2013):

- Aggregating maintenance and renewal costs to the operation costs of the network (traffic management, capacity management, administration costs and so on). The aggregation may be justified in so far as operation costs (i.e. signalling, traffic control and planning) and maintenance costs are running costs for the infrastructure manager, but whereas the former are practically fixed [95% fixed, according to ORR (2005)], the latter are largely variable costs [up to 30%, according to Thomas (2002)], and therefore processing them and subsequently levying them on railway undertakings should be done separately. Therefore, on the basis of the above, the operation costs should be estimated first, and then subtracted from the aggregate cost before proceeding to process the maintenance and renewal costs.

- Aggregation with enhancement and upgrading costs. Enhancement and upgrading costs should be considered as investment costs, since they mean adding new functionalities to existing infrastructure (enlargement of capacity, enhanced safety and so on).
- Aggregation of track-related costs to electrification system costs (e.g. catenary and substations). Wear and tear and the costs generated by this subsystem are different for tracks, so they should be processed separately. Moreover, diesel trains have no reason to pay for the maintenance of the electrification system.

Taking this preliminary situation into account, only maintenance and renewal costs will be considered below, with a view to promoting the transparency of train running charges. Therefore, the other costs involved in providing infrastructure (i.e. administration, planning, signalling, congestion and investment costs) should be processed separately to design a comprehensive charging regime (aggregating additional charges – fixed and/or variable – and/or mark-ups). A comprehensive charging regime design goes beyond the scope of this paper.

3. A proposal for processing and allocating maintenance and renewal costs

3.1. Costs processing proposal

Taking the interval of time between two renewals as a study period, the cumulated load on the track would make maintenance operations increasingly frequent and more important, whereas the quality of the track would diminish (EPFL 2003).

If traffic increases during the study period more than estimated and there is an attempt to keep the track up to a certain degree of quality, the time interval between successive maintenance operations will diminish, and so will the life cycle of the renewal (t). Therefore, the maintenance and renewal costs for a specific time interval will increase, in the same way that a decrease in traffic would have the contrary effect.

When processing the costs between two consecutive renewals (illustrated in Figure 1), certain aspects should be taken into consideration:

- Planned preventive maintenance operations can be considered as costing the same (m_p would be their annual cost).
- Renewal costs operations (R) tend to be considerably higher than corrective maintenance costs operations (M_i).
- The life cycle of corrective maintenance operations (t_i) is shorter than the life cycle of renewal operations (t), so $t_i < t$. n correction maintenance operations are considered before the subsequent renewal operation, so $t = \Sigma t_i; i = 0, 1, \ldots, j, \ldots, n$.
- The more accumulated traffic on a track, the more and faster it deteriorates, and therefore maintenance costs increase throughout the track's life cycle.
- In practice, the renewal of a section of track is usually used as an opportunity not only to renew its parts, but also to replace them with higher-quality parts (a heavier rail, rigid fastening for elastic fastening, wood sleepers for concrete sleepers, increased ballast thickness and so on). Enhancement and upgrading (E&U) instead of renewal alone may be justified by the fact that the increase in cost as compared to a mere renewal is not very high and helps to extend life cycle

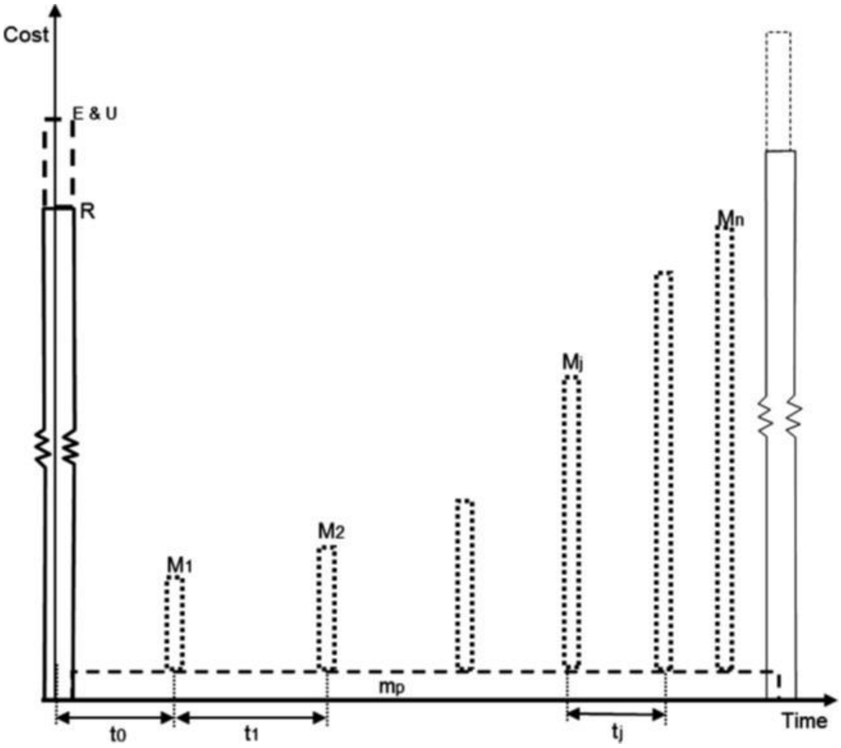


Figure 1. Calendar of maintenance and renewal operations.
Note: E&U, R and M_i in €; m_p in €/year; t_i in years.

and lower maintenance costs. Renewing a track with a UIC-71 rail instead of a UIC-60 rail, for instance, implies a 17% cost increase (Baumgartner 2001). Moreover, if a technical progress clause exists, the renewal will go hand in hand with an enhancement.

According to the above, and considering a uniform distribution of costs throughout the life cycle of each operation, costs will evolve as shown in Figure 2.

If this cost history was transposed directly to a railway undertaking, it would give an increasingly higher pricing level for the train running charge between two renewals. However, there are several factors that advise against using this variable pricing (Calvo et al. 2013):

- Uncertainty with regard to the price of the charges arising from cost variation (much steeper towards the end of life cycle) might pose a barrier to railway undertakings right from the start.
- The utility of infrastructure to a railway undertaking evolves conversely (and, therefore, decreases) to the evolution of the cost involved. This is so because infrastructure provides the best conditions of strength and geometry when it is new. Moreover, tracks become less reliable and the increasing need for maintenance operations may make them less available as their life cycle advances, which could cause delays and capacity constraints. Thus, along tracks' useful life,

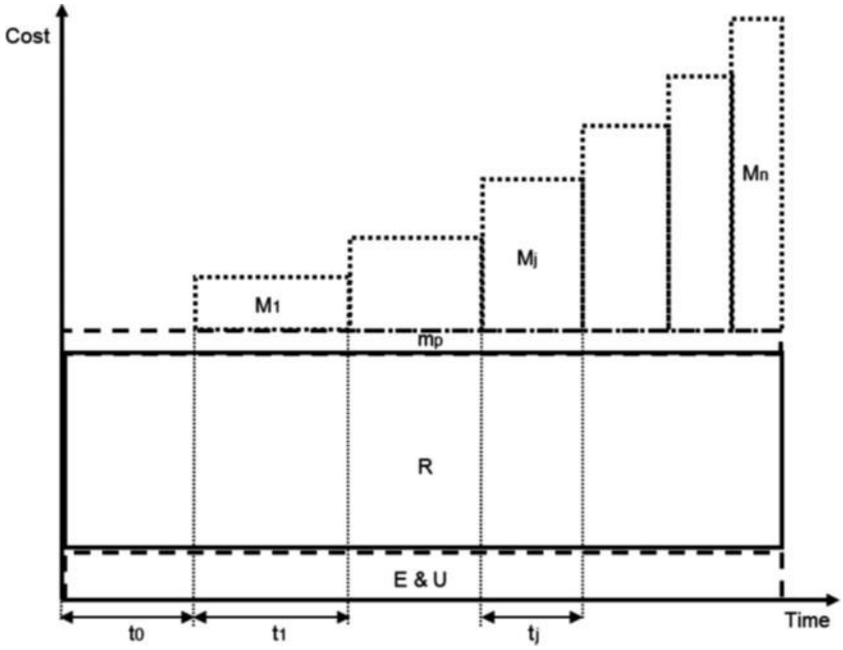


Figure 2. Evolution of costs between two renewals, uniformly distributed.
Note: E&U, R and M_i in €; m_p in €/year; t_j in years.

> maintenance operations can be seen as a necessary evil, because maintenance assures performance (Nyström and Söderholm 2010).

Thus, taking utility into consideration, the pricing level between two renewals should diminish rather than increase. As a compromise that would reconcile the two conditioning factors (increasing costs and declining utility) and give a measure of stability to charges related to maintenance and renewal costs, this paper proposes a method in which cost distribution would be more balanced, as shown in Figure 3.

The cost distribution shown in Figure 3 has been obtained by adopting a decreasing cost distribution for the renewal cost (R) and superimposing a uniform distribution of costs for maintenance operations (M_i). This decreasing cost distribution can be obtained by using an accelerated depreciation method, in which higher amounts of depreciation are charged in the earlier years and lower amounts in the later years of a fixed asset's life. Many assets (such as railway infrastructure) are more efficient and most useful when they are new, so a higher depreciation expense can be levied in the early years. Over time, depreciation expense moves in a downward direction and maintenance costs tend to become higher (Siegel and Shim 2005). Thus, in this proposal, the increase in maintenance costs towards the end of a track's life cycle is compensated by a reduction in the charges owing to the renewal's depreciation. If enhancement and/or upgrading occur along with the renewal, the associated increase in cost should be treated separately, as an investment cost.

Currently, RailCalc (CENIT et al. 2007) and similar projects are recommending activity-based costing (ABC) to levy the incremental operational costs (i.e. maintenance, renewal and signalling). As for cost assessment, the RailCalc project recommendation is

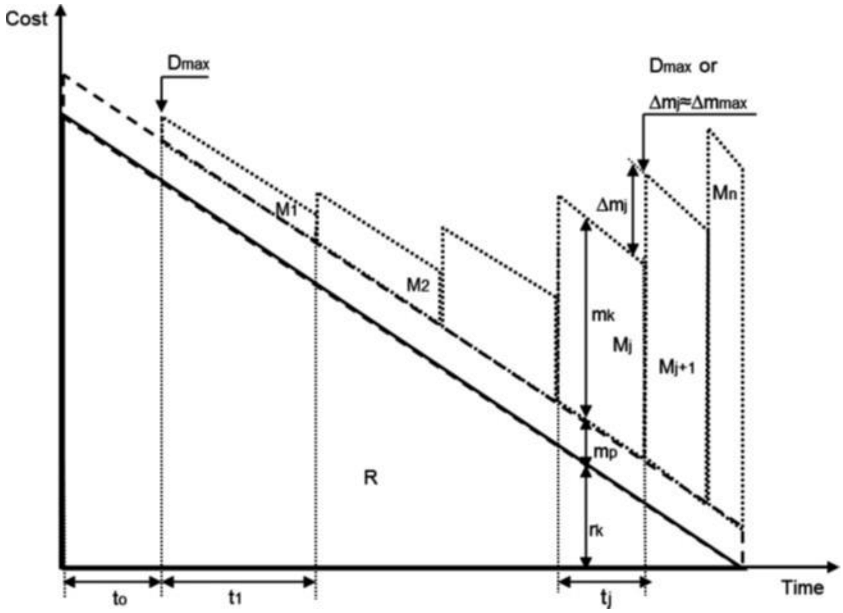


Figure 3. Proposal for cost depreciation between two renewals.
Note: R and M_i in €; r_k, m_p and m_k in €/year; t_i in years.

to consider a dynamic forward-looking approach to current and future costs preferable to historical costs. The reason for this approach lies in the fact that basing current and planned costs on the estimated level or service and production could be an incentive to improve infrastructure management.

As explained below, the cost distribution shown in Figure 3 is based on actual and estimated costs, and would provide a more stable pricing level in the middle term – compared to the uniform distribution of costs shown in Figure 2 – thereby making it easier to implement the ABC method. It would still be convenient, however, to keep historic data in mind. The method proposed would also bring the pricing level more in line with the quality of service given to the operator, so the charges obtained would be more market oriented. The steps needed to arrive at the proposed cost distribution are given below. Renewal cost processing requires middle- and long-term planning:

(1) R: renewal cost. A given datum, since it is an operation that marks the beginning of the analysis period.
(2) t: life cycle of the renewal. Historical data need to be used for estimating this time interval. Values in Table 1 could be used as reference.
(3) Distribute the renewal cost according to a decreasing depreciation method based on R and t.

Maintenance costs require short-term planning:

(1) The annual cost of preventive maintenance (m_p) can be easily estimated on the basis of planned diagnosis work.
(2) Setting a track quality standard, associated with the maximum deterioration allowed (D_{max}).

Table 1. Life cycle of a renewal operation.

		Traffic (single track)		
GTK/day × 10^3	10	30	100	300
GTK/year × 10^6	2.5–3.6	7.5–11	25–36	75–108
Track with rail		Life cycle of the renewal (years)		
UIC 54	40	20	10	–
UIC 60	–	25	12	6
UIC 71	—	—	—	7

GTK = gross tonne-kilometre.
Source: Baumgartner (2001).

(3) The first corrective maintenance operation (i = 1) should be performed when track deterioration approaches D_{max}. The maintenance operation's useful life (t_1) ends when a new D_{max} is attained. The operation's real cost (M_1) and its useful life can be used to calculate the annual cost:

$$m_1 = M_1 / t_1 \quad (1)$$

This datum (or from any m_j) can be used to estimate the annual maintenance cost for subsequent periods, as described step-by-step below.

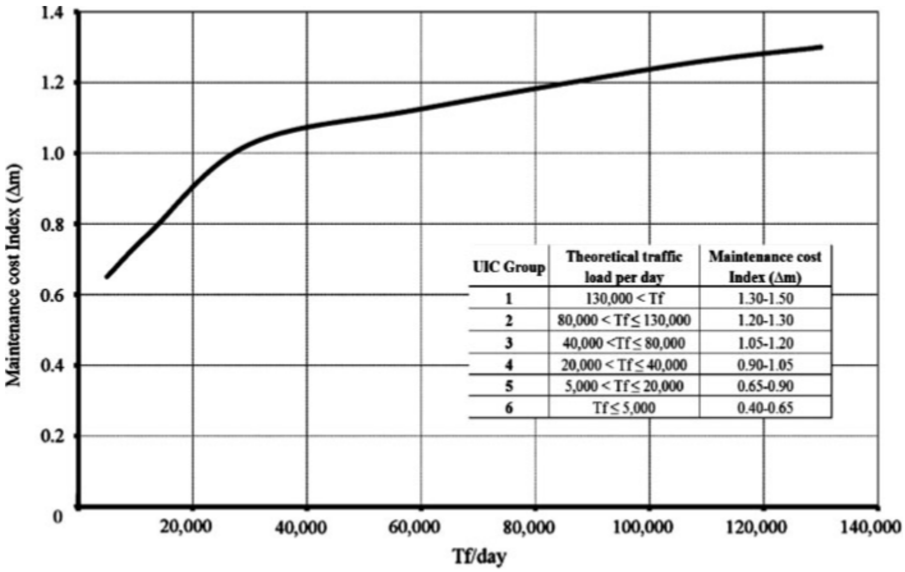
(4) The estimated maintenance costs for subsequent periods (m_{j+1}) can be calculated on the basis of how they compare to the previous cost (m_j), which in turn depended on how traffic evolved during the previous period ($(\Delta_{traffic})_j$). The theoretical traffic load can be used to estimate how much maintenance costs will vary with the level of traffic. This concept, which relates a train's key features to maintenance costs, and the corresponding cost studies (UIC 1989, 1992) were developed by the Way and Works Group of the International Union of Railways (UIC). The variation of the annual cost of maintenance (Δm) as compared with the development of the theoretical traffic load $(\Delta Tf/day)_j$ can be obtained from Figure 4.

The curve in Figure 4 was obtained by taking the middle point of each theoretical traffic load (Tf) interval for each UIC Group (with the exception of groups 1 and 6, where the minimum and maximum traffic was taken, respectively) in the axis of abscissas and the variation in the maintenance cost as it goes from one Group to another, according to Leaflet 715 R (UIC 1992), in the axis of ordinates.

From Figure 4, it can be inferred that if increases in traffic are related to the growth in costs, the latter will increase more slowly at higher traffic levels. That implies that the cost per unit of maintenance decreases with the level of traffic. This is the characteristic of railway infrastructure, which moves in the area of growing average yields.

Thus, the estimated maintenance cost for the following period is obtained by multiplying the variation (taking the Index in Figure 4) by the cost of the previous period.

$$m_{j+1} = m_j (1 + \Delta m)_j \quad (2)$$



UIC Group	Theoretical traffic load per day	Maintenance cost Index (Δm)
1	130,000 < Tf	1.30-1.50
2	80,000 < Tf ≤ 130,000	1.20-1.30
3	40,000 <Tf ≤ 80,000	1.05-1.20
4	20,000 < Tf ≤ 40,000	0.90-1.05
5	5,000 < Tf ≤ 20,000	0.65-0.90
6	Tf ≤ 5,000	0.40-0.65

Figure 4. Variation of annual maintenance cost with theoretical traffic load (Tf), based on UIC (1992).

where the maintenance cost variation is based on how traffic evolves during the current period:

$$\Delta m_j = f(\Delta Tf/day)_j \tag{3}$$

The estimated life cycle for the next period (t^{e}_{j+1}) would be given by:

$$t^{e}_{j+1} = M_{j+1}/m_{j+1} \tag{4}$$

where M_i $(i = 1, 2, \ldots, j, j+1, \ldots, n)$ is the real cost of each maintenance operation.

(5) The real life cycle of each one of the operations (t_j) will be given by one of two conditions:
- Deterioration close to D_{max}.
- An increase in maintenance costs up to a value close to the maximum acceptable value $(\Delta m_j \approx \Delta m_{max})$.

(6) To determine the last maintenance operation before the next renewal, an associated cost limit (M_n) needs to be set.

Thus, the annual cost associated to maintenance and renewal operations during any k year $(r_k + m_p + m)_k$ for the period of time concerned is obtained (as shown in Figure 3).

In Figure 3, the end of the renewal's life cycle coincides with the end of the last maintenance operation's life cycle. In other words, the renewal has been amortised by the end of the track's life cycle. If this forecast is not met, adjustments can be made in two cases:

- Case 1: Track deterioration sooner than forecasted (M_{rr} is reached before getting to t). The renewal cost that remains to be amortised may be carried over to the next period.
- Case 2: Track deterioration is slower than estimated (the renewal is amortised before M_{rr} is reached). In this case, the pricing level of the train running charges at the end of the track's life cycle could be lowered, or a minimal pricing for renewal costs, to be discounted in the next period, could be considered.

Similar corrections need to be made for any maintenance operations whose useful life does not match the estimated life $(t_j^e \neq t_j)$.

3.2. Costs allocation proposal

A top-down method that takes into account the main cost drivers may be used to levy maintenance and renewal costs. Maintenance and renewal costs increase with static and dynamic loads on the track, and also according to a path's characteristics. Thus, with regard to a train's features, maintenance and renewal costs:

- Increase with the train's total weight, since heavier trains cause higher loads on the track.
- Increase with a train's axle load. Therefore, self-propelled trains, being lighter than conventional trains, cause lower maintenance and renewal costs because their traction tends to be more distributed, making their maximum load per axle lighter.
- Increase with unsprung mass, whose weight has a direct, unmitigated impact on the track, thereby increasing the dynamic loads.
- Diminish when the suspension system is improved (by installing pneumatic suspension, for instance).
- Increase with traffic speed, because dynamic loads increase with traffic speed.
- With regard to paths, maintenance and renewal costs:
- Diminish with improvements to the path's layout. More moderate gradients and wider curves diminish lengthwise and crosswise stress on tracks.
- Diminish with the strength of the track. Heavier rails, concrete sleepers, ballast border thickness of more than 30 cm and better quality subgrade increase track strength as a whole, so train traffic causes less wear and tear.
- Increase with the infrastructure's age, since maintenance operations are more frequent. Old tracks are more prone to deformations that increase dynamic loads, which in turn accelerate wear and tear.
- Increase in high-speed paths for daily inspection and maintenance operations to ensure security when running at high speeds increases maintenance costs (Baumgartner 2001).

In European charging systems, basic parameters [train-km and gross tonne-kilometre (GTK)] are used to levy maintenance and renewal costs. Sometimes other aspects are also considered, such as speed, axle load, train type, traffic type (mainly passenger/goods) and the quality of the infrastructure (normally, the price increases with the quality of the infrastructure; Calvo and de Oña 2005).

However, this price modulation is not always transparent. It does not show how variations in price are calculated and it gives rise to fixed prices at intervals, which may cause distortions in the market. Instead of the price modulation option, the proposed method suggests starting with the cost for each type of path (namely high speed, upgraded or conventional paths) and levying charges according to a simple formula that reflects the trains key wear- and tear-related features (weight, speed and axle load).

To do so, the wear and tear caused by each train could be related to the theoretical traffic load (Tf) it generates (UIC 1989):

$$Tf = S\,(Tv + Kt\,Ttv) + S\,(Kg\,Tg + Kt\,Ttg) \qquad (5)$$

where:

S coefficient that increases from 1.00 for speeds under 60 kph up to 1.50 for speeds above 250 kph;
Tv weight in tonnes of the passenger cars;
Kt coefficient allowing for the traction-motor axle wear factor, and is equal to 1.40;
Ttv weight in tonnes of the tractive unit, in passenger trains;
Kg coefficient allowing for the influence of the axle loads of goods wagons. Increases from 1.15 to 1.45 with the axle load;
Tg gross tonnes hauled, in goods trains;
Ttg weight of the locomotive in goods trains.

Passenger multiple units with concentrated traction (normally, axle loads of more than 17 tonnes) may be included in the tonnage of tractive units (Ttv), whereas lighter multiple units with more distributed traction (usually, axle load of <17 tonnes) should be included in Tv.

The variables on which Tf depends can be easily known to the railway undertaking and the infrastructure manager, since speed can be considered the average speed and Km will depend on the load transported by the train.

Using this parameter requires turning traffic (i.e. train-km or GTK) into notional traffic (Tf-km), finding the equivalence of each train in Tf and multiplying the result by the distance covered. The process can be simplified by using the more typical trains.

To meet the aims of cost adjustment, data availability and charging system simplification, incremental costs can be levied on the basis of their share of the total cost, instead of calculating a cost function, with the difficulty and relative degree of closeness to reality that implies, or carrying out a study of bottom-up costs.

The average cost (€/Tf-km) can be obtained by dividing the annual maintenance and renewal costs ($r_k + m_p + m_k$) for a path (or a network, if no cost breakdown is available) by the annual theoretical traffic. Next, multiplying the average cost by the Tf equivalent for each train will give the total traffic-related cost of each train (€/km), and therefore a closer idea than the train-km or GTK (Calvo, de Oña, and Nash 2007). Once each traffic-related cost has been obtained, the pricing level can be set between the incremental costs (taking around 20% of the total cost) and the total cost taking into consideration some aspects related to rail infrastructure capacity and the railway undertaking's willingness to pay (Quinet 2003; Calvo and de Oña 2012a).

4. Sample calculation of proposed train running charges

A practical application of the proposed method is given below to illustrate how the train running charges can be obtained from data on 14 European railway networks.

The Lasting Infrastructure Cost Benchmarking (LICB) study (UIC 2008) will be used as a benchmark for traffic and cost data. This study is an international benchmarking project developed by the Infrastructure Commission of the UIC. Currently, 14 European infrastructure managers (IM) participate in the project (Austria, Belgium, Denmark, Finland, Germany, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Sweden, Switzerland and the UK) and deliver information each year. Data have been collected and analysed since 1996. The benchmarking area of LICB is maintenance, and renewal expenditures are jointly analysed as an integrated life cycle-cost approach for entire railway networks. Data collection and analyses are carried out by the Infrastructure Department of the UIC. Work was monitored and assisted by the working group of IM's from the participating railways.

According to the data in the LICB Report (UIC 2008), average annual traffic is 16,810 train-km/km, of which 17% are goods trains, 28% are long-distance trains and 55% are local and regional trains. The trains' average weight can be taken as 920, 590 and 270, respectively (ECMT 2005). These data can be used to obtain the weighted average weight of a train. The weighted average weight is multiplied by the average annual traffic to obtain the annual traffic in GTK per kilometre of main track: 7884.43 GTK/km (Table 2).

The life cycle of renewal is obtained from annual traffic in GTK/km and Table 1. On the basis of average annual traffic in the countries that took part in the LICB Report (7.88×10^{6} GTK/km) and assuming that the track is equipped with a UIC 60 rail, the useful life would be 25 years.

Concerning costs, the LICB Report is considering harmonising the method for comparing cost data from different countries that take into account network configurations and the circumstances under which they are operated. Aspects of infrastructure complexity (single vs. multiple track, switch densities, etc.) and track utilisation, together with purchasing power parities, are taken into account. On the basis of the data, the Report obtains average annual costs of €38,200/km for renewal operations and of €40,000/km for maintenance. The development of the overall cost shown in Figure 5 was obtained by taking the average costs and distributing them evenly throughout the useful life of each renewal and maintenance operation.

The distribution of running costs during a track's useful life was obtained by considering preventive maintenance costs as a uniform annual cost and six corrective maintenance operations in which costs increase and useful life diminishes. Maintenance costs during the first few years were considered preventive maintenance. As Figure 5 shows, a track's annual cost grows when a uniform cost distribution is used, just as the train running charges would.

Table 2. Calculation of annual traffic in GTK, based on UIC (2008) and ECMT (2005) data.

	Traffic composition	Weight	Weighted average	Traffic	
Rail service	%	t	t	Train-km/km × 1000	GTK/km × 1000
Local and regional passenger trains	55	270	469.03	16.81	7884.43
Long-distance passenger train	28	590			
Goods train	17	920			

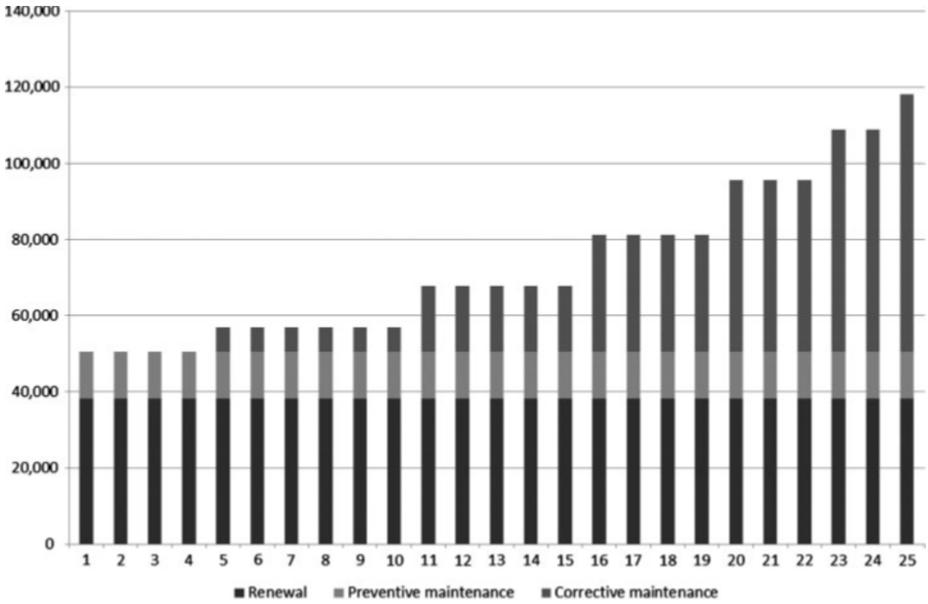


Figure 5. Changes in track total cost (€/km) according to a uniform depreciation of renewal.

On the contrary, if decreasing depreciation of renewal is considered (e.g. Sum-Of-The-Years'-Digits Method), as suggested in this article, the cost distribution obtained will be as shown in Figure 6.

As Figure 6 shows, the decreasing distribution of renewal costs tends to compensate the increase in the maintenance cost, and therefore the total annual cost (used to set the train running charges) gains in stability throughout the track's useful life. The area in the upper part of the chart can be integrated up the maximum annual cost in each case to verify that the proposed method is more stable. This will show that the variation of the total annual cost when using a uniform distribution is three times higher than it would be if the decreasing distribution had been used. Moreover, the maximum annual cost is also much lower in the latter case. To conclude, the suggested method allows a more uniform distribution of track costs and lowers the highest value.

These two effects can be used to give the train running charges stability throughout a track's useful life and to mitigate its highest value. Despite any adjustments that may be required during a track's useful life (arising from failed estimations of t and t_i), the proposed method leads to more stable train running charges and reduces uncertainty in the tariff rates, at least in part. Thus, it may prove to be an incentive for new railway undertakings entering the market. On the other hand, the proposed charging system is more market-oriented because train running charges and utility for the railway undertaking are more closely related.

The train running charge for any given year (in year K = 13, for instance) is calculated below. Figure 6 gives $r_{13} + m_{p} + m_{13}$ = €38,200 + 12,308 + 17,310 per km = €67,818.21 per km.

Transferring the cost to railway undertakings would require knowing the characteristics of the traffic. The data can be taken from previous years (K = 11, 12 and so on), based on the estimated progressive changes. First, traffic is broken down into the various

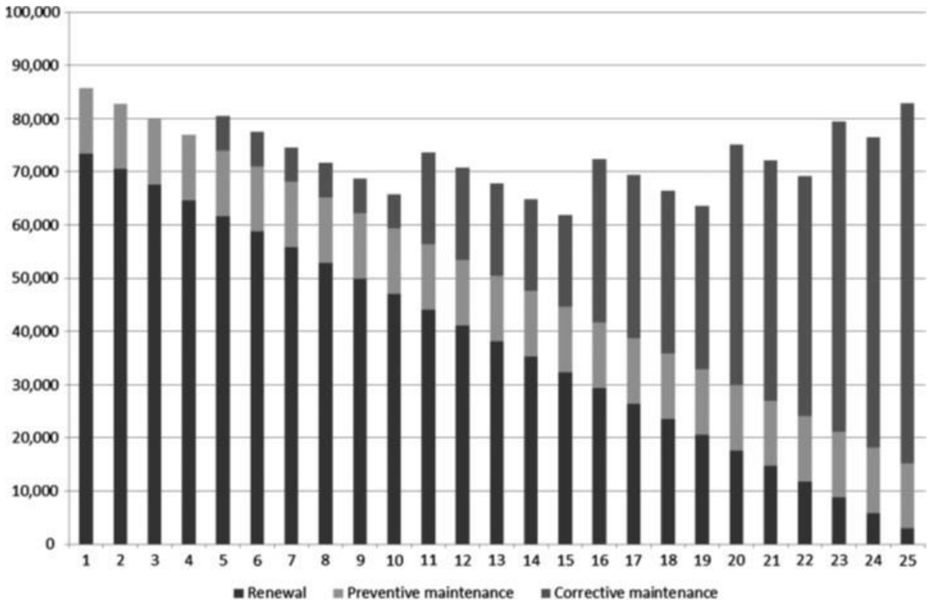


Figure 6. Changes in track total cost (w) decreasing depreciation of renewal.

rail services that operate in the railway line. Taking average traffic and the composition of traffic in the LIBC Report (UIC 2008) as benchmarks, it is found that: 9301 train/km corresponds to local and regional services, 4651 train/km to long-distance rail services and 2858 train/km to goods rail services.

Next, a benchmark train type is selected for each rail service, and its equivalence in terms of theoretical traffic load (Tf) is calculated. Table 3 shows that goods trains cause the most track wear and tear according to the notion of theoretical traffic load. They are followed by conventional long-distance trains and local multiple train units. This is due to the indicator's impact on axle load, hauled weight, concentrated traction and speed. The theoretical traffic load generated by each rail service is obtained by multiplying actual traffic by the notional traffic.

Table 3 leads to the conclusion that although local and regional rail services support most of the actual traffic, they have the lowest theoretical traffic load, which means they cause less track damage. This is because suburban and regional trains use to be multiple train units (and these kind of train sets are lighter than conventional trains and their traction is distributed) and they run at moderate speeds.

Next, the annual cost in year 13 ($r_{13} + m_{p} + m_{13}$ = €67,818.21 per km) is divided by the total traffic estimated for the same year (10,037,119 Tf-km/km, from Table 3) to obtain the unit total cost, which amounts to 0.0068 per Tf-km. Finally, the unit total cost is multiplied by each train's equivalent Tf to obtain the total cost generated by each train (Table 4).

If costs are distributed according to the theoretical traffic load, it is found that suburban trains generate the lowest maintenance and renewal costs, followed by long-distance trains (2.7 times higher) and goods trains (1.7 times higher than long-distance trains and 4.7 times higher than suburban trains).

Table 3. Equivalence by train type and calculation of theoretical traffic load (Tf), based on UIC (1989, 2008) and ECMT (2005) data.

Rail service	Train	Average running speed (km/h)	S	Kg	Tv or Tg	Kt	Ttv or Ttg	Tf/train	Train-km/km	Tf-km/km
Local and regional passenger trains	Multiple train unit	80.00	1.05	0.00	270.00	0.00	0.00	283.50	9301	2,636,969
Long-distance passenger train	Conventional train	106.67	1.25	0.00	504.00	1.40	86.00	780.50	4651	3,629,915
Goods train	Conventional train	66.67	1.05	1.30	875.00	1.40	85.00	1319.33	2858	3,770,235
									Total traffic	10,037,119

Table 4. Calculation of running charges per rail service.

Rail service	Train	Tf/train	€/Tf-km	Total cost (€/train-km)	Marginal cost (€/train-km)
Local and regional passenger trains	Multiple train unit	283.50	0.0068	1.92	0.38
Long-distance passenger train	Conventional train	780.50	0.0068	5.27	1.05
Goods train	Conventional train	1319.33	0.0068	8.91	1.78

Therefore, if train running charges are levied according to the highest pricing level (total cost), the train running charges payable in year 13 for suburban, long-distance and goods trains would be €1.92, €5.27 and €8.91per train-km, respectively. If the lowest pricing level is considered and train running charges are levied according to incremental cost, the train running charges would be lowered to 20% of the total cost (assuming that is the fraction of the total cost).

The final train running charge price, to be set somewhere between these two extremes, would depend on the desired target level of cost recovery. When setting the train running charges somewhere between the incremental cost and the total cost, certain other aspects should be taken into consideration as well: railway undertakings' willingness to pay [a combination of auctioning and central planning by the infrastructure manager could be the method to approach this matter, according to Quinet (2003)], aspects related to rail infrastructure capacity, the public nature of certain rail services and certain traffic's contribution to the sustainability of the transport system as a whole (Calvo and de Oña 2012a). If this decision is taken, any costs not covered by the charging system would have to be financed by the government, as occurs in practice in the European countries that recover 5–65% of the infrastructure cost (ECMT 2005). This approach is consistent with Directive 2001/14/EC, which says that if the market cannot bear the total cost, the gap between the marginal and total cost should be subsidised by the government.

Finally, the values obtained for the train running charges can be compared to similar charges given in the Network Statements of some countries (shown in Table 5). To do this, the so-called 'usage charges' (mainly related to the maintenance and renewal costs caused by train traffic, but frequently related to administrative, traffic management and scarcity costs as well) can be identified with the calculated running charges at marginal cost level, and the 'full charge' (equal to the sum of all charges payable by the train operator) can be identified with charges running at total cost level. Before proceeding to a comparison, it should be mentioned that it is only an approximate comparison.

Taking the running charges payable in year 13 as a benchmark for the European countries, it can be said that, considering the running charges at the total cost level, one point in common among all countries is the small portion of maintenance and renewal track costs recovered via charges (except for the local and regional passenger trains). Furthermore, both in terms of marginal cost and in terms of total cost, cost recovery is generally higher for the local and regional trains than for any other train.

Likewise, the lowest level of cost recovery is applied to goods trains. The pricing level on long-distance passenger trains is in the intermediate range. According to Table 5, costs are generated in reverse order to the pricing level applied, so obviously price discrimination

Table 5. Comparison between running charges for the 13th year and rail charges in some European countries.

	Local and regional passenger trains		Long-distance passenger train		Goods train	
	Usage charge	Total charge	Usage charge	Total charge	Usage charge	Total charge
Belgium	0.313	2.607	0.313	4.514	0.313	1.651
Germany	2.130	5.272	2.470	4.076	2.130	2.130
Italy	3.844	6.406	1.741	2.902	1.445	2.408
Austria	1.229	1.581	1.565	1.621	1.953	1.953
Denmark	0.263	0.263	0.263	3.538	0.263	0.263
Finland	0.350	0.350	0.761	0.761	2.138	2.138
Portugal	1.370	1.370	1.380	1.380	1.100	1.100
Sweden	0.639	0.639	1.313	1.313	0.569	0.569
Switzerland (SBB)	1.838	1.838	3.097	3.097	2.629	2.629
UK	0.773	0.887	2.251	2.365	3.109	3.109
The Netherlands	0.949	1.447	1.502	1.616	2.142	2.142
Average charge	1.245	2.060	1.514	2.471	1.617	1.827
Running charge	0.38	1.92	1.05	5.27	1.78	8.91

Source: Calvo and de Oña (2012b).

is occurring. It may be the consequence of a certain degree of cross-financing. Thus, generally speaking, local and regional rail services would be cross-financing infrastructure and the other rail services (Calvo and de Oña 2012b). This gives an idea of the indirect subsidies that the overall goods trains receive through rail charges in most of the countries.

5. Conclusions

Infrastructure managers need to distinguish between operational costs and asset-related costs if they are to contribute to charging system transparency. Asset-related costs should make a distinction between investment cost items (including construction, upgrading and enhancement) and maintenance and renewal for the different railway subsystems (infrastructure, electrification, signalling, etc.).

This article suggests train running charges to recover maintenance and renewal costs. The price of the charges should be based on the way costs evolve throughout a track's useful life.

Corrective maintenance operations become progressively more frequent and more expensive in the course of a track's useful life, so a uniform distribution of track maintenance and renewal costs gives a growing distribution of costs, with the increase being much steeper towards the end of the track's service life. However, levying the track costs on railway undertakings between two renewals should take into consideration that the track's utility for the operator diminishes towards the end of its service life (as does the quality of the track).

Therefore, when faced with the dilemma posed by an increasing pricing level (due to increased maintenance costs) and a decreasing pricing level (in relation to utility), this paper proposes a method that provides for a more uniform distribution of track-related costs between two renewal operations (compared with using an overall uniform distribution of costs). The method consists in distributing the cost of the renewal operation according to a decreasing depreciation method and superimposing the cost of the) maintenance operations on it, uniformly distributed. Thus, the distribution of diminishing renewal costs compensates the increase in maintenance costs.

With the proposed method, the train running charge gains stability in the course of the track's useful life and reaches a lower maximum value. This could be an incentive for new railway undertakings entering the market, because it tends to diminish uncertainty with regard to the charging level in the middle term. Thus, the train running charges obtained are also more market-oriented, because they take into consideration the utility perceived by the railway undertaking.

Moreover, because it is based on the current and forward-looking costs for track expenses associated with current and estimated traffic levels, the proposed system may be viewed as an incentive for infrastructure managers to become more efficient. The suggested cost planning is based on a track's standard of quality and the way traffic evolves, using UIC's theoretical traffic load concept.

In Europe, the current practice is to use simple parameters to levy track usage costs (train-km, GTK), occasionally modulating prices according to several aspects, such as speed, the category of the train and the type of traffic. Normally, several different costs are included in a single track charge (e.g. maintenance, administrative costs, signalling and traffic planning). This method is not transparent and may cause distortions on the market.

In view of this situation, this paper proposes using a dedicated charge, known as a train running charge, to levy track usage cost. As a simplified method of calculation, this paper recommends starting with the cost according to the category of the line (mainly high speed/upgraded/conventional) and using a top-down approach based on a levying parameter that includes key cost-drivers. The parameter proposed is again the theoretical traffic load, which relates the running of the train with the cost generated and, therefore, it also contributes to increase the charging system's transparency. Using a single indicator (theoretical traffic load) to plan costs and transfer them to the railway undertakings helps to simplify the processing of train running charges.

After calculating the total annual track cost, the price of the train running charges can be set between the incremental cost and the total cost, according to the objectives of cost recovery. The increase in prices over the marginal costs should be set on the basis of the ability to pay of each railway service. Setting charging levels should also take into consideration the nature of some railway services as a public service and their contribution to the transport system's sustainability.

In the sample calculation, actual data have been used to verify the benefits of applying the suggested train running charges. The breakdown shows that goods trains cause the most track wear and tear, according to the notion of theoretical traffic load. They are followed by long-distance trains and regional and suburban trains. Thus, the highest costs can be attributed to goods trains, long-distance trains and regional and suburban trains, in that order. Moreover, different levels of cost recovery can be achieved by applying the two extreme charging levels (full cost/incremental cost).

For example, the running charge at marginal cost could be used as usage charge while positives or negatives mark-ups (e.g. for priority in circulation, contribution to sustainable transport, etc.) would establish the total charge closer to of further from the total running cost. Thus, the highest values of the obtained train running charges for long-distance trains (at the total cost level) could be identified with the mark-ups applied in certain countries.

Finally, the results obtained for the running charges show that, in general, charging systems reach a low level of cost recovery (except in the case of local and regional passenger trains) and that the highest cost allocation is applied to local and regional trains, while the lowest cost allocation is applied to goods trains, when costs are generated in reverse order. This may be a consequence of the subsidised willingness to pay of the local and regional services (keep in mind that the local and regional rail services are well funded by public authorities and provide a secure source of financing for infrastructure managers).

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