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### Transport infrastructure evaluation using cost-benefit analysis: improvements to valuing the asset through residual value—a case study

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Abstract: Residual value (RV) is an important component of Cost Benefit Analysis (CBA), often valued at 20% to 50% of total construction costs. It is often overlooked which can artificially depress the project's returns. The treatment of RV is inadequate and needs further research. Residual value represents the value of the infrastructure at the end of its project lifetime and the value that the asset generates from then on. We analyze three methods for calculating RV: straight-line depreciation, annuity/perpetuity and component.

The straight-line depreciation method is the most commonly used; it is simple and quick to produce and it typically uses a percent of the total construction cost rather than real value. The perpetuity/annuity method ignores the actual value of the asset. It reflects the difference of costs and benefits between economic and useful life (annuity method) or assumes an infinite economic life (perpetuity method). The component method is the most detailed and difficult to calculate method. It gives the actual value of the physical asset at the end of project appraisal by infrastructure component. We assume three scenarios for the future for the component method.

We use the case study of the Portuguese High Speed Rail project to calculate and compare each method. As expected, the perpetuity has the highest RV and net present value (NPV), followed by the annuity method and then the component method. The straight-line method produces the lowest values (other than one scenario for the component method).

Sensitivity analysis is performed *ceteris paribus* for the demand, construction cost and discount rate factors. We conclude that RV is important in situations when the benefit-cost ratio is close to 1 and the method selected can have a large impact on the size (and sign) of the NPV.

Jones, Domingos, Moura and Sussman

1 **Transport infrastructure evaluation**  
2 **using cost-benefit analysis:**  
3 **improvements to valuing the asset**  
4 **through residual value - a case study**  
5

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## 1 **ABSTRACT**

2 Residual value (RV) is an important component of Cost Benefit Analysis (CBA), often valued at  
3 20% to 50% of total construction costs. It is often overlooked which can artificially depress the  
4 project's returns. The treatment of RV is inadequate and needs further research. Residual value  
5 represents the value of the infrastructure at the end of its project lifetime and the value that the  
6 asset generates from then on. We analyze three methods for calculating RV: straight-line  
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11 and benefits between economic and useful life (annuity method) or assumes an infinite economic  
12 life (perpetuity method). The component method is the most detailed and difficult to calculate  
13 method. It gives the actual value of the physical asset at the end of project appraisal by  
14 infrastructure component. We assume three scenarios for the future for the component method.

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16 method. As expected, the perpetuity has the highest RV and net present value (NPV), followed  
17 by the annuity method and then the component method. The straight-line method produces the  
18 lowest values (other than one scenario for the component method).

19 Sensitivity analysis is performed *ceteris paribus* for the demand, construction cost and discount  
20 rate factors. We conclude that RV is important in situations when the benefit-cost ratio is close to  
21 1 and the method selected can have a large impact on the size (and sign) of the NPV.

22 **Keywords:** Cost benefit analysis, transport infrastructure, residual value, straight-line  
23 depreciation, component method, Portuguese High-speed railway.

24

## 1 INTRODUCTION

2 Cost Benefit Analysis (CBA) is the most widely used evaluation framework for investment  
3 projects such as transport infrastructure (Munger, 2000; Nickel, Ross & Rhodes, 2009; Valentin  
4 et al, 2009). It is used because it is a comprehensive evaluation tool (Munger, 2000; Pearce et al,  
5 2006; ITF, 2011), it may lead to efficient allocation of resources (World Bank, 2004; Ackerman,  
6 2008; Ninan, 2008), and it accounts for both socioeconomic and financial costs and benefits  
7 (Pearce et al, 2006; World Bank, 2004; Ninan, 2008; Guhnemann, 1999; Beder, 2000; Vining  
8 and Boardman, 2005). However, currently and in practice, the most compelling reason for its use  
9 is that many governments and agencies require CBA for final approval of projects. For European  
10 Union (EU) member states, CBA is required for funding from the Instrument for Pre-Accession  
11 countries, Cohesion Fund or Structural Funds. Governments and agencies in the U.S., Canada  
12 and Netherlands require CBA for many infrastructure projects. The OECD (1969), UN (1972)  
13 and World Bank (1975) use CBA as part of their funding process mechanism. The United  
14 Nations (UN) requires CBA for financial support applications (Mishan and Quah, 2007).

15 As global population growth inherently increases demand on and for transport infrastructure, and  
16 with the size of projects soaring, properly evaluating the costs and benefits of the investment is  
17 required for the most efficient use of scarce funding resources (World Bank, 2004; Ackerman,  
18 2008; Ninan, 2008). Some impacts are adequately covered by CBA while others leave areas for  
19 improvement. Residual value (RV) is one of such cases and it is a critical factor in CBA. It is  
20 critical for large investment projects such as transport infrastructure because it represents the  
21 value of the infrastructure at the end of the project lifetime, theoretically equal to the value that  
22 the asset will generate from then on (Jones et al 2014). RV is of particular importance in  
23 concessionaire situations. It can indirectly stipulate the quality of service and the state and  
24 functionality of the infrastructure at the end of the concession period. Infrastructure projects with  
25 large hazardous wastes or cleanup costs can have a negative RV (idem). RV can be the critical  
26 value in a CBA, changing the sign of the net present value (NPV) (Matrai, 2012). It is often  
27 overlooked or simply omitted during CBA, artificially depressing project returns (Florio and  
28 Vignetti, 2003; Lee Jr., 2002).

29 The main objective of this paper is to analyze the treatment of infrastructure's residual value in  
30 more depth, by comparing two additional calculation methods along with the most common  
31 approach of straight-line depreciation. The first section of this paper provides an introduction to  
32 CBA. Section 2 introduces residual value and its related concepts of depreciation, discount rate  
33 and project lifetime. The third section puts forward three methods to calculate RV, straight-line  
34 depreciation, annuity/perpetuity and component. Section 4 presents the case study of the High  
35 Speed Rail project in Portugal and the results produced from using each of the three methods.  
36 The fifth section sets forth a sensitivity analysis to highlight the situations in which RV is more  
37 important and Section 6 provides conclusions.

## 2 Residual Value, Related Concepts and State of Practice

### 2.1 Residual value

RV represents the infrastructure's value at the end of its projected lifetime. It is accounted for in the final year of the CBA and can also be interpreted as the value generated by the asset after the end of the project lifetime. It does not actually have to be sold, for example in the US, rail lines have been used for 150 years without being sold at the end of the project analysis. However, depending on the method, the use after the end of the analysis (continue using versus scrap) may change the value. It is not discounted until the NPV is calculated for all of the costs and benefits in the CBA. It is a benefit (usually expressed as a negative cost) that is an input into the total costs and benefits which are then discounted. Properly accounting for this will show the true value of the asset. Often, RV is overlooked during CBA, which artificially depresses the projects returns (Florio and Vignetti, 2003). As such, current methods for calculating RV do not properly reflect the value that the asset generates after the end of the project's lifetime. The RV of the project investment is the remaining value of the investment at the end of the project lifetime (standing debt and standing assets such as buildings or machines). It can be calculated as the residual market value of fixed capital as if they were sold at the end of the time horizon of the project. The discounted value of every net future receipt after the time horizon should be included, making it the same as the liquidation value (EC, 2008).

However, it is often calculated differently in practice, as the present value (PV) of expected net cash flows during the years of economic life outside the reference period if the economic life exceeds the project lifetime period (EC, 2008). Another method calculates it as the estimated amount that an entity would currently obtain from disposal of the asset, after deducting the estimated costs of disposal, if the asset were already of the age and in the condition expected at the end of its useful life (IASB, 2006; Edgerton, 2002). Since there are different assets (e.g., tracks, buildings, etc.), it is difficult to arrive at an accurate value for RV for the overall infrastructure.

RV is often ignored in infrastructure CBAs. Table 1 presents some references on how RV has been approached for transportation infrastructures. RV is of particular importance in concessionaire situations. It can indirectly stipulate the quality of service and the state and functionality of the infrastructure at the end of the concession period. Infrastructure projects with large hazardous wastes or cleanup costs can have a negative RV. A prime example is the decommissioning costs for a nuclear power plant, usually quite considerable (Rogers and Duffy 2012) or for large expenditures like major re-landscaping (RAILPAG 2005).

**TABLE 1 Residual Value in Transportation Infrastructure Literature**

Source	Position
Lee Jr., 2002	Some investments continue infinitely and should have a RV calculated for them.
EC, 2008	Economic life of the project and RV for any useful assets after time horizon.
Odgaard, Kelly, and Laird, 2006	RV is composed of the lifetime of the infrastructure and the depreciation profile. The treatment varies by country.
Campos, de Rus, and Barron, 2007	RV is difficult to calculate because rail has different assets with different useful lives and depreciation rates.
Annema, Koopmans, and van Wee, 2007	RV calculations should be transparent.

EC and EIB RAILPAG, 2005	RV should be calculated individually for the different components of the infrastructure.
ACT, 2008	RV should be calculated using different lifetimes for the following key components: fixed infrastructure (tracks and tunnels), earthworks and drainage, stations and rail cars.
RITES and Silt, 2010	RV is calculated for each infrastructure item.

1  
2 The literature agrees that RV should be included in CBA. Although not exhaustive, the  
3 cases reviewed and posted in the table above suggest that decomposing the analysis of the RV  
4 for the different components of the infrastructure might overcome some of the drawbacks  
5 pointed in the literature. It would help to account for the different components and to increase  
6 transparency.

## 7 2.2 Depreciation

8 Sections 2.2 and 2.3 discuss several concepts that are intertwined with RV. Depreciation is the  
9 process of allocating the costs of using an asset over its useful life. The project lifetime is the  
10 period of project analysis and may be shorter than usual life directly implying that the remaining  
11 value between the two should be accounted for. The discount rate is used to determine present  
12 value and the choice of rate has a direct impact on the value after discounting.

13 Depreciation measures and spreads over time the costs associated with consuming an asset over  
14 its useful life. It is the systematic allocation of the depreciable amount of an asset over its useful  
15 life. The depreciable amount is the cost of an asset less its residual value (or, equivalently, the  
16 residual value of an asset is equal to its cost minus its depreciable amount). Useful life is the  
17 period over which an asset is expected to be available for use by an entity (SALG, 2009) which  
18 may be shorter than its physical life. Physical life is the potential service life of an asset before it  
19 physically becomes unable to produce a good or service. The terms economic and useful life can  
20 be used interchangeably (EC, 2008). Since depreciation concerns using up an asset the method  
21 used should reflect the pattern in which it is being used. Technical and commercial obsolescence  
22 such as potential changes in consumer demand should be taken into account in this regard.

23 Depreciation is typically calculated in one of three ways. The first and most commonly  
24 used method is 'straight-line' (Casares and Coto-Millan 2011). It uses only age of the asset and  
25 assumes that the consumption of the asset is constant over time (Woodward 1956) it should be  
26 used for projects that have a short and predictable useful life (SALG 2009) such as equipment at  
27 airports and ports. The second method is condition based (idem). It uses only the physical  
28 condition of the asset. It is most commonly used when evaluating road pavement by creating a  
29 degradation profile that correlates the physical condition to an estimated total life cycle (ibidem).  
30 The third method is consumption based which uses the assets' remaining service potential after  
31 taking into account both aggregate and component specific factors (ibidem) and should be used  
32 for more complex infrastructure projects.

## 33 2.3 Discount Rate and Project Lifetime

34 The lifetime of a project varies by sector and individual project. It begins when the  
35 project becomes operational and it ends when it is shut down (Lee Jr., 2002). The economic  
36 lifetime of a project ends when the annual cost of keeping it in service is greater than the

1 annualized cost of replacing it (Mackie and Preston, 1998; Lee Jr., 2002). This culminates in  
 2 either termination through selling off any still useable assets for their market value or by  
 3 continuation through continual replacement. The time frame ranges from as little as a year to  
 4 infinity although most CBAs use a project lifetime that is shorter than the physical lifetime. It  
 5 should at least be long enough to see stabilization of traffic growth (RAILPAG 2005). Highways  
 6 are usually continually improved giving them an effectively infinite lifetime while equipment is  
 7 usually salvaged or discarded after a given time period. Buildings such as stations and vehicles  
 8 are somewhere in between as they can receive improvements indefinitely or can be salvaged or  
 9 torn down.

10 The discount rate and project lifetime used in CBA can impact whether a project has a  
 11 positive or negative Net Present Value (NPV). A high exponential discount rate could reduce  
 12 even a large RV benefit into an insignificant amount especially depending on the project  
 13 lifetime. The discount rate can have a large impact on the RV and the appropriate discount rate  
 14 should be given much consideration (Matrai 2012). The project lifetime is important because the  
 15 longer the lifetime the lower the RV due to depreciation and then it is discounted for a longer  
 16 time.

## 17 2.4 State of Practice

18 Table 2 reviews some methods used to calculate RV in the infrastructure sector.  
 19 Assumptions on percentage of total construction budget, discount rate and project lifetime are  
 20 also presented.

21 **TABLE 2. Residual Value Methods and Assumptions**

RV Method	Infrastructure Sector	Residual Value	Discount Rate	Project lifetime
No RV	Freight Transfer Center <sup>a</sup>	No RV due to low discount rate	4%	25 years
	High Speed Rail <sup>a</sup>	No RV	4%	25 years
	Road and Transport <sup>a</sup>	No RV	4%	40 years
		No RV	7% for transport benefits	
	Urban Development <sup>a</sup>	No RV-Infinite lifetime	4%	Infinite
Waterway Deepening <sup>a</sup>	No RV-Infinite lifetime	7% for transport and land benefits		
	No RV	3%-4%	25 years	
Annuity	High Speed Rail <sup>b</sup>	No RV	4%	50 years after completion
		No RV	4% with 7% for benefits	Infinite
Perpetuity	New Road <sup>c</sup>		10%	Infinite
Straight-Line	Airport Extension <sup>a</sup>		4%	38 years
	Freight Rail <sup>a</sup>	35% of construction costs	4%	35 years
		40% of construction costs	4%	35 years
	High Speed Rail	30% <sup>d</sup> of construction costs	5% <sup>d</sup>	40 years <sup>d</sup>
		35% <sup>d</sup> of construction costs	4% <sup>d</sup>	30 years
	10% <sup>e</sup> of construction costs	Not used <sup>e</sup>	40 years <sup>e</sup>	



	costs			
	20% of construction costs <sup>f</sup>	5% <sup>f</sup>		35 years <sup>f</sup>
High Speed Rail Link <sup>a</sup>	35% of construction costs	4%		30 years
Light Rail <sup>g</sup>		No discount rate <sup>**</sup> )		30 years
	Fixed Infrastructure			100 years
	Earthworks and Drainage			40 years
	Stations			50 years
	Rail Cars			35 years
Port Entrance <sup>a</sup>	Not defined	4%		20, 35, 60 years and no RV
Port Extension <sup>a</sup>	*)	4%		30 years
Rail “Do-minimum” Line Upgrade <sup>h</sup>	20% of construction costs	3%		40 years
Rail Level Crossing Elimination	40% of construction costs	3%		20 years
Rail Line Renewal	10% of construction costs	5%		38 years
Rail Line Upgrade	50% of construction costs	3%		40 years
Rail Link <sup>a</sup>	35% of construction costs	4%		30 years
Rail Link to Terminal	50% of construction costs	5%		65 years
Rail Terminal Development	50% of construction costs	3%		50 years

1 Notes: \*) Balance of advantages and disadvantages for last 10 to 15 years of lifetime; \*\*) Used straight line  
 2 depreciation of actual acquisition costs; a) Annema et al, 2007; b) ACG, 2013; c) Casares and Coto-Millan, 2011; d)  
 3 Campos et al, 2012; e) Republic of Serbia, 2012; f) RAVE, 2009; g) ACT, 2006; h) RAILPAG, 2005

4

### 5 3 METHODS TO CALCULATE RESIDUAL VALUE

#### 6 3.1 Straight-Line Depreciation Method

7 In order to simplify calculations, straight-line depreciation is the most commonly used method  
 8 for calculating RV (ACG, 2013) where RV is equal to the non-depreciated amount of the asset. It  
 9 can be calculated for any given year. Although it is not the best nor the most comprehensive  
 10 method, it can be calculated quickly and easily and it can be used as a point of comparison with a  
 11 more comprehensive and intensive method. Age is the only consideration in this method (SALG,  
 12 2009). The cost of using the asset is allocated solely based upon time and assumes use is  
 13 constant. It is not adjusted for differences in consumption or condition. For CBAs that use the  
 14 straight-line depreciation method, different rates of depreciation are used (Table 2) typically as  
 15 some % of initial construction costs. It is calculated from the remaining service life (RSL) as:

16

17

18

**EQUATION 1 Straight-Line Depreciation Method**

$$RV = \frac{RSL}{total\ service\ life} * initial\ capital\ cost$$

**3.2 Annuity and Perpetuity Methods**

The difference between discounted costs and benefits, after the end of the project, as an annuity or in perpetuity is another method sometimes used for calculating RV. This method ignores the actual value of the asset and only considers the net of costs minus benefits. Some critics argue against this method as it presumes a steady state where expenditures on the asset are not necessarily recognized as enhancing the future economic benefits of the asset (SALG, 2009).

The annuity version is chosen for assets that have a specific lifetime that is past the project time period (e.g. 40 years lifetime for a project that is evaluated for 30 years would have a 10 year annuity). To determine the RV using the annuity method the difference between the costs and benefits are discounted over the difference between the useful life and the physical life of the asset. It is calculated as:

**EQUATION 2 Annuity Method**

$$PV = C \times \left[ \frac{1 - (1 + i)^{-n}}{i} \right]$$

, where the present value (PV) equals the cash flow (C) which is the net of benefits and costs,  $i$  is the discount rate and  $n$  is the number of payments (years).

The perpetuity method would be used for projects that are assumed to have an infinite lifetime such as one that can be prolonged by maintaining it. The operating period for the perpetuity method is irrelevant (RAILPAG 2005). It is calculated as:

**EQUATION 3 Perpetuity Method**

$$PV = \frac{C}{(1+r)^1} + \frac{C}{(1+r)^2} + \frac{C}{(1+r)^3} \dots = \frac{C}{r}$$

, where the present value (PV) equals the cash flow (C) which is the net of benefits and costs and  $r$  is the discount rate. The perpetuity method is equal to the limit of the annuity method when  $n$ , the number of periods, goes to infinity.

**3.3 Component Method**

Another method of calculating RV for infrastructure is by calculating a RV for each infrastructure component and then summing the components to get the total RV (Rites & Silt, 2009). This is certainly a more robust calculation than simply assuming one rate for the entire project because it considers more than just age, it considers consumption of each component and is the most transparent. By calculating the residual value through its asset components and using more thorough methods to determine discount rates and project lifetimes, a more accurate RV

1 can be included in CBA. This is effectively a modified consumption based depreciation method  
2 (SALG 2009).

3 For example, in the case of high-speed rail, calculating RV through its components would  
4 include signaling, electrical, catenary, earthworks, structures, track and stations/buildings and  
5 their required replacement schedules. This requires a maintenance and replacement schedule for  
6 the components that gives each component a different lifetime. These lifetimes must be synced  
7 to the total project lifetime. Depending on these schedules some of the components have a longer  
8 lifetime than the project which can increase the RV of the asset over the straight-line  
9 depreciation method. Table 3 refers to the recommended rate of residual value for components  
10 (Rites & Silt, 2009).

11

12 **TABLE 3. Residual Value of Infrastructure Items**

Infrastructure Item	Rate of Residual Value (after 30 years)	Total Lifetime (years)
Land and Associated Activities	80%	150
Earthwork	50%	60
Protection Works	50%	60
Blanketing	50%	60
Bridges	50%	60
P. Way	20%	38
Station and Buildings	50%	60
Tunnels	50%	60
Electrical	30%	43
Signaling and Telecom	20%	38
Maintenance Facilities (Electrical and Mechanical)	40%	50

13 Source: Rites & Silt, 2009

14 RV encompasses more than just the asset components. It includes land and also materials  
15 that can be salvaged during replacement, expansion/upgrades or demolition/sell off. The value of  
16 land will often appreciate over time. Steel and iron prices fluctuate and can potentially be a  
17 source of income at the project lifetime if dismantled (or sold during replacement). The risk of  
18 new technology such as Maglev making the investment obsolete and reducing the RV to only  
19 selling off the pieces as scrap, should be considered.

20

## 21 **4 THE CASE OF HIGHSPEED RAIL PROJECT IN PORTUGAL**

### 22 **4.1 Case study description**

23 For the case study the Portuguese HSR CBA from Rede Ferroviária de Alta Velocidade (RAVE)  
24 (RAVE, 2009) will be used and will be referred to as Portuguese High Speed Rail (PHSR). Full  
25 information is available in RAVE's report (RAVE, 2009). It is a large-scale transportation  
26 infrastructure project that is one of the 30 priority projects of the Trans-European Transport  
27 Network (TEN-T) program of the European Commission. The line would cost roughly €4.5

1 billion and would be 297 kilometers long and include 5 stations (Lisbon, Leira, Coimbra, Aveiro  
2 and Porto). The link between Lisbon and Porto would have a maximum speed of 300 kilometers  
3 per hour and is estimated to take 1 hour and 15 minutes with speeds of 240 kilometers per hour  
4 on services without intermediate stops. The PHSR has 5 years of construction followed by 35  
5 years of operation.

6 In order to calculate the costs and benefits for the CBA, the difference between the “Do-  
7 Minimum” (DM) and “Do-Something” (DS) was used by RAVE and represents the data used.  
8 Data for “Do-Nothing” was not available. All values for RV and NPV are in thousands. The DM  
9 alternative includes the high speed (HS) links between Lisbon and Madrid and between Porto  
10 and Vigo. The DS alternative includes those two links plus a HS link between Lisbon and Porto.  
11 Since the only difference is the HS link between Lisbon and Porto, these are the only values that  
12 need to be determined.

13 The DM alternative includes the high speed (HS) links between Lisbon and Madrid and  
14 between Porto and Vigo. The DS alternative includes those two links plus a HS link between  
15 Lisbon and Porto. Since the only difference is the HS link between Lisbon and Porto, these are  
16 the only values that need to be determined.

## 17 4.2 Straight-line results

18 The case study CBA (PHSR from RAVE 2009) uses a discount rate of 5% and assumed  
19 RV to be 20% of the initial construction investment (straight-line depreciation method). RV is an  
20 input and is not discounted until the NPV calculation. Construction costs were €4,670,386  
21 including the Lisbon and Porto stations. The RV was €934,877 and NPV was €3,047,785. The  
22 authors also constructed a new discount rate for comparison. The new rate was calculated by  
23 using the risk free rate represented by the average 10 year German bond over the last 20 years  
24 (4.4%) plus the Beta for the rail sector (0.55) multiplied by the market risk premium (11.9%  
25 average 20 year DAX return minus the risk free rate 4.4%=7.5%) which equals 8.5%. The NPV  
26 was calculated at the discount rate of 8.5% which resulted in €670,330.

27 **TABLE 4. Cumulative Total Benefits and Costs (calculated based on RAVE 2009)**

Description	Cumulative Total (in € 000s)
<b>External Benefits</b>	
Net User Vehicle Operating Costs (excl. HSR)	8,553,827
Net Travel Time Savings	8,617,511
Accidents	477,003
Net Externalities	468,069
Direct Employment Benefits	2,450,471
Wider Economic Benefits	3,395,954
Total External Benefits	23,962,835
Discounted External Benefits	7,468,376
<b>Capital and Investment Costs</b>	
Fixed Assets	3,387,411
Rolling Stock Acquisition	668,034
Replacement Costs	1,531,972
Operating Costs	3,203,207
Residual Value	-934,877

Total Capital and Investment Costs	7,855,747
Discounted Capital and Investment Costs	4,420,785
Difference between Discounted External Benefits and Discounted Capital and Investment Costs (NPV)	3,047,785

1  
2 For comparison purposes NPV was calculated using €0 for RV and 5% and 8.5% as the  
3 discount rate. NPV was €2,927,336 and €639,942, respectively.

#### 4 4.3 Annuity and Perpetuity Results

5 In order to use the annuity method the physical lifetime is estimated to be 50 years. A physical  
6 lifetime of 50 years is reasonable and conservative as many of the conventional tracks that are  
7 being used in Europe and the U.S. were built 150 years ago and maintained over that period as  
8 well. The RV is the difference between costs and benefits for the period after the project lifetime  
9 and the end of the physical lifetime. The future costs and benefits for a period of 15 years after  
10 the 35 year lifetime were estimated to be a constant annuity stream. The discount rate was kept at  
11 the same 5% that was used in the study and the new interest rate that was constructed (i.e., 8.5%)  
12 was also used. Using the 5% discount rate the RV is €8,303,421 and NPV is €3,997,145. Both  
13 the RV and NPV are higher than using the original straight-line method. At 8.5%, RV is  
14 €6,643,145 and NPV is €855,877.

15 In order to use the perpetuity method the difference between costs and benefits in the final  
16 year were assumed to be constant as a reflection of business as usual by that time. Both the 5%  
17 and 8.5% discount rates were used. At 5%, RV is €15,999,412 and NPV is €4,988,412. As  
18 expected both RV and NPV are higher than the original method and the annuity method. At  
19 8.5%, RV is €9,411,419 and NPV is €945,860. Both comparisons are presented in Table 5  
20 below.

#### 21 4.4 Component Method Results

22 The RV was calculated using the different lifetimes and depreciation rates for each of the  
23 components. The component lifetimes were determined using both the RITES and Silt (2010)  
24 and RAILPAG (2005) guidelines. RV was calculated using three different sets of assumptions.  
25 The cumulative construction costs and renovation and repair expenditures are in Table 5.  
26 Renovation and repair was considered as a renewal to the investment, increasing the depreciated  
27 value (but not increasing the lifetime due to lack of specificity in the data) (RAILPAG 2005,  
28 SALG 2009, Matrai 2012) and had variable lifetimes between 10 and 25 years depending on the  
29 timing and level of investment. Maintenance was not considered a renewal.

30 **TABLE 5. Cumulative Construction Costs**

Construction Category	Cumulative Total Cost (in €s)
Demolition	4,148,841
Expropriations	219,123,279
Affected Services	48,559,768
Earthworks	364,053,313
Drainage	77,318,765
Re-establishments	58,766,806
Small Bridges	110,077,656

Bridges and Viaducts	751,755,495
Tunnels	705,175,981
Retention and Support	69,971,391
Environment Protection	89,473,924
Track	320,937,735
Catenary	134,935,382
Signal and Telecom	256,388,491
Substation	42,510,708
Stations	73,308,147
Power Lines	34,279,947
Construction Contingency	672,157,126
Project Contingency	282,305,993
Lisbon Station	219,578,581
Porto Station	135,559,001
Renovation	633,763,241
Repair	8,923,563

1 Scenario 1 assumed that land did not depreciate and was worth the same as its initial  
2 investment. The track was assumed to depreciate at a normal rate with a lifetime of about 40  
3 years (plus repair and renovation investments increasing the value) and that there was a market  
4 for the asset at the end of the appraisal period. This resulted in RV of €2,506,599 and NPV of  
5 €3,250,285 at 5% and €721,419 at 8.5%.

6 Scenario 2 included the land appreciating to twice the initial investment (Martinez 2010,  
7 NAR 2012) by the end of the 40 years. It also included the same assumptions about the track as  
8 in Scenario 1 above but and also that the materials prices made it worth about the initial  
9 investment. It also assumed that there was a market for the investment. This resulted in RV of  
10 €3,024,194 and NPV of €3,316,972 at 5% and €738,243 at 8.5%.

11 Scenario 3 assumed that there was not a market for the asset (Maglev or new technology  
12 being the only investments made). The land and some materials have some value bringing the  
13 RV to €540,061 and NPV to €2,996,917 at 5% and €657,496 at 8.5%. The land is assumed to  
14 remain at the level of the initial investment (no depreciation or appreciation) and the track is  
15 assumed to be worth the same level as investment due to the fact that steel and iron ore prices  
16 can be extremely volatile (Plaizer and Nachtergaele 2010).

17 The results for RV and NPV for all of the methods are compiled in Table 6.

18 **TABLE 6. Residual Value and Net Present Value by Method**

Method	Pros	Cons	RV (in €000s)	NPV 5% (in €000s)	RV (in €000s)	NPV 8.5% (in €000s)
Omitted	Easiest, very fast	Gives no remaining value to the asset unjustified	0	2,927,336	0	639,942
Straight-Line	Simple, quick	Typically uses a % of total construction cost rather than real value	934,877	3,047,785	934,877	670,330
Annuity	Reflects difference of costs and benefits between	Ignores actual value of asset	8,303,421	3,997,145	6,643,145	855,877

Perpetuity	economic and useful life Reflects difference of costs and benefits as if economic life is infinite	Ignores actual value of asset		15,999,412	4,988,412	9,411,419	945,860
Component	Gives actual value of physical asset at end of project appraisal	More difficult to calculate	Scenario 1	2,506,599	3,250,285	2,506,599	721,419
			Scenario 2	3,024,194	3,316,972	3,024,194	738,243
			Scenario 3	540,061	2,996,917	540,061	657,496

1

## 2 5 SENSITIVITY ANALYSIS

3 Sensitivity analysis was performed *ceteris paribus* on each of the demand, discount rate and  
4 construction costs factors. It was performed for each of the three methods (straight-line, annuity  
5 and perpetuity and the three different component scenarios) and also using no RV (RV equal to  
6 zero). The importance of the discount rate was discussed in section 2.3. Demand and  
7 construction cost estimates are known to be often wrong and by a large margin (Mayer and  
8 McGoey-Smith, 2006; OECD, 2006; Rasouli and Timmermans, 2012; Skamris and Flyvbjerg,  
9 1997; World Bank, 2005), so it is important to know the impact of changes to these estimates on  
10 RV and thus NPV. These changes can turn the NPV sign to negative which influences policy  
11 conclusions about the project.

12 For traffic demand, the no RV and straight-line methods' NPVs were negative (or nearly)  
13 and the benefit/cost ratio (B/C ratio) at almost 1 when demand was at 60% of the estimate. All  
14 scenarios of the component method were negative at 75% of the estimate and had a B/C ratio of  
15 less than 1. The annuity and perpetuity methods remained with positive NPVs and B/C ratios  
16 well above 1 (between 1.22 and 1.93). For large projects, traffic forecasts are commonly  
17 incorrect and off by 20% to 60% when compared to actual development (Skamris and Flyvbjerg,  
18 1997) and projects such as the Calcutta metro had only 8% of forecast traffic in the opening year,  
19 the Channel tunnel had 18%, the Miami metro had 15% and the Paris Nord TGV had 25%  
20 (Flyvbjerg et al 2003) showing that inaccuracies of this magnitude are possible. While some of  
21 these were ramp-up problems, others such as the Calcutta metro continue to be plagued by  
22 extremely low ridership (about 9% of the forecast amount (Godard and Fatonzoun 2002)).

23 Costs are often underestimated (Mayer and McGoey-Smith, 2006; OECD, 2006; Rasouli  
24 and Timmermans, 2012) and overruns of 50% to 100% are common with some above 100% not  
25 uncommon (Skamris and Flyvbjerg, 1997). The no RV and straight-line methods' NPVs were  
26 negative (or nearly) and the benefit/cost ratio (B/C ratio) at almost 1 when forecasts were 112%  
27 above the estimate. All scenarios of the component method and the annuity method were  
28 negative (or nearly) at 150% of the cost estimate and had a B/C ratio of equal to or less than 1.  
29 The perpetuity method remained with a positive NPV and a B/C ratio well above 1 (1.16).

30 All of the methods except for perpetuity had very low NPVs and B/C ratios near 1 using a  
31 10.75% discount rate. All of the methods had negative NPVs and B/C ratios below 1 using a  
32 12% discount rate. Higher discount rates can reduce the value of even a large RV (i.e. perpetuity

1 method) to an insignificant amount and can even change the sign of the NPV. Much  
2 consideration should be given to the choice of the discount rate.

3 The authors conclude that RV has a larger impact when the benefit to cost ratio is closer to  
4 1. When the ratio is near 1, the RV has the ability to change the sign of the NPV (refer Table 7).  
5 The factor assumptions and RV method chosen has a large impact on the project NPV which can  
6 lead to different policy conclusions.

7



1 **TABLE 7. Sensitivity Analysis of Benefit/Cost Ratio and Net Present Value**

		NO RV (RV=0)	Straight Line	Annuity	Perpetuity	Component 1	Component 2	Component 3
		B/C Ratio NPV	B/C Ratio NPV	B/C Ratio NPV	B/C Ratio NPV	B/C Ratio NPV	B/C Ratio NPV	B/C Ratio NPV
<b>Base Case</b>		1.64 2,927,336	1.69 3,047,785	2.15 3,997,145	3.01 4,988,412	1.77 3,250,285	1.80 3,316,972	1.67 2,996,917
<b>Demand</b>	-25%	1.42 1,788,753	1.46 1,909,203	1.89 2,858,563	2.74 3,850,112	1.53 2,111,703	1.56 2,178,389	1.44 1,858,335
	-50%	1.16 650,171	1.2 770,620	1.58 1,719,981	2.39 2,711,529	1.26 973,120	1.29 1,039,807	1.18 719,752
	-60%	<b>0.99</b> <b>-32,978</b>	<b>1.02</b> <b>87,471</b>	1.45 1,264,548	2.22 2,256,097	1.14 517,688	1.17 587,374	1.07 264,320
	-75%	0.87 -488,411	0.90 -367,962	1.22 581,399	1.93 1,572,942	<b>0.95</b> <b>-165,462</b>	<b>0.97</b> <b>-98,775</b>	<b>0.89</b> <b>-418,830</b>
<b>Construction Costs (Fixed Assets)</b>	+25%	1.43 2,263,704	1.47 2,384,153	1.81 3,333,513	2.38 4,325,062	1.53 2,586,653	1.55 2,653,340	1.45 2,333,285
	+50%	1.27 1,600,072	1.3 1,720,521	1.56 2,669,882	1.96 3,661,430	1.35 1,923,021	1.36 1,989,708	1.29 1,669,653
	+112%	<b>0.99</b>	<b>1.01</b>	1.16	1.37	1.04	1.05	<b>1.00</b>

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		<b>-45,735</b>	<b>74,714</b>	1,024,075	2,015,623	277,214	343,901	<b>23,846</b>
	+150	0.88	0.89	<b>1.00</b>	1.16	<b>0.91</b>	<b>0.92</b>	<b>0.88</b>
		-1,054,455	-934,006	<b>15,354</b>	1,006,903	<b>-731,506</b>	<b>-664,819</b>	<b>-984</b>
<b>Discount Rate</b>	5%	1.64	1.69	2.15	3.01	1.77	1.80	1.67874
		2,927,336	3,047,785	3,997,145	4,988,412	3,250,285	3,316,972	2,996,917
	8.5%	1.19	1.20	1.30	1.41	1.22	1.23	1.20
		639,942	670,330	909,845	1,160,003	721,419	738,243	657,496
	10.75%	<b>1.00</b>	<b>1.00</b>	<b>1.04</b>	1.08	<b>1.01</b>	<b>1.01</b>	<b>1.00</b>
		<b>-5,082</b>	<b>7,751</b>	<b>108,896</b>	214,536	<b>29,325</b>	<b>36,430</b>	<b>2,331</b>
	12%	0.91	0.92	<b>0.94</b>	<b>.96</b>	<b>0.92</b>	<b>0.92</b>	<b>0.92</b>
		-224,732	-216,723	<b>-153,594</b>	<b>-87,661</b>	<b>-203,257</b>	<b>-198,823</b>	<b>-220,105</b>

1

## 2 6 CONCLUSIONS

3 Properly accounting for RV is a key element when performing CBA (Annema, Koopmans and  
 4 van Wee, 2005; Laurentiu 2011). Tables 6 and 7 presented the results for each of the methods  
 5 used and corresponding sensitivity analysis to critical variables. As expected, the perpetuity  
 6 method has the highest RV (over 17 times higher than straight-line), NPV (64% higher than  
 7 straight-line) and B/C ratio (3.01). The annuity method has the second highest levels of RV  
 8 (almost 9 times higher than straight-line), NPV (31% higher than straight-line) and B/C ratio  
 9 (2.15). The component method produces a slightly higher RV and NPV than the straight line  
 10 method. The first component scenario method has the second highest levels of all of the  
 11 component methods of RV (almost 3 times higher than straight-line), NPV (7% higher than  
 12 straight-line) and B/C ratio (1.77). The second component scenario method has the highest levels  
 13 of all of the component methods of RV (over 3 times higher than straight-line), NPV (9% higher  
 14 than straight-line) and B/C ratio (1.80). The third component scenario method has the lowest  
 15 levels of all of the component methods of RV (42% lower than straight-line), NPV (2% lower  
 16 than straight-line) and B/C ratio (1.67).

17 The authors prefer the component method because although it is more detailed and complex, in  
 18 the end, it also makes the accounting procedure more transparent and might bring positive  
 19 contributions for the purpose of contract negotiation (e.g., PPP's) since breaking down the cost  
 20 structure of RV is more defensible than making bundled assumptions for the infrastructures' RV,  
 21 as is the case of straight-line depreciation or some % of initial cost. The authors believe that the  
 22 component method better reflects the true value of the asset as it shows what each component is  
 23 worth at the end of the appraisal period. It also takes into account the value of land and the prices  
 24 of materials. However, the component method is quite complex, time consuming and requires a  
 25 high level of detailed estimates. In some situations such as a quick screening among many  
 26 alternatives, a simpler method might be preferred.

27 In this case study, changing the value of the RV did not change the final decision of the  
 28 cost benefit analysis, although critical variables can shift NPV from positive to negative,  
 29 resulting in opposite conclusions regarding the investment decisions. Likewise, in other  
 30 infrastructure projects where RV value represents a high percent of the total costs and benefits  
 31 such as hazardous waste facilities, it can change the sign of the NPV (Matrai, 2012; Laurentiu,  
 32 2011).

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