Determinants of Rail Rolling Stock Value

An analysis of the determinants of locomotive and freight wagon value
in the European market

Maxime Bonnier
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DETERMINANTS OF RAIL ROLLING STOCK VALUE

AN ANALYSIS OF THE DETERMINANTS OF LOCOMOTIVE AND FREIGHT WAGON VALUE IN THE EUROPEAN MARKET

FRONT COVER

LOCON 9905 in the evening sun at the temporary container terminal in Almelo on March 21, 2012. This locomotive started its second life through a second-hand transaction, 29 years after the manufacturer completed it. Built by Alsthom for Dutch national operator NS in 1982, locomotive 1836 was sold to private rail freight operator LOCON Benelux B.V. in October 2011. Subsequently, the locomotive was repainted and renumbered in 9905. In September 2017, when LOCON Benelux B.V. faced bankruptcy, Rotterdam-based rail fleet management company RailReLease B.V. acquired it. At that time, locomotive 9905 was still going strong at an age of 35 years, showing the potential of second-hand rail vehicles.

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Henk Zwoferink Fotografie

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PREFACE

The completion of this thesis marks the end of an important chapter in my life, as it is the end of my time as a student at the Delft University of Technology. At the same time, the page is turned to a new exciting chapter, as it flags the start of a professional career. It would never have been possible for me to write this thesis without the encouraging support, guidance and advice from others. First, I would like to express my gratitude to Wouter Radstake from DVB Bank SE and Bernd Wagner from Beacon Rail Leasing Ltd. for their time and willingness to support by giving insight in some general aspects of the practice of rail vehicle valuation. Finally, I would like to thank my supervisors for their time, constructive feedback and advice.

On a more personal note, I would especially like to express my gratitude to my parents Hans and Marianne Bonnier for the at times much needed motivation, their trust, tips and tremendous support. Special thanks also go out to Dr. Lee Bouwman and Vivian Bouwman for their motivational speeches and advice. Furthermore, I must thank Denisa Krechlerová for her help with the translation of Czech documents containing rolling stock data that proved difficult to translate using digital tools alone and Henk Zwoferink for making a cover photo available. Finally yet importantly, I would like to thank all other family members and friends that have supported me during the writing of my final work at the Delft University of Technology.

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ABSTRACT

Liberalisation of the rail market in Europe has made the rail vehicle market more dynamic. Since the nineteen-nineties, the European Economic Community (now the European Commission) has aimed at increasing the competitiveness of rail transport. By reducing entrance barriers and increasing interoperability of the rail system, the number of active operators received a boost. The development of standardized vehicle platforms for Europe-wide operations and the creation of rail vehicle leasing companies has further facilitated the entry of new rail operators to the market.

DVB Bank (Metz & Radstake, 2013) estimates that the total investment in new rail vehicles in Europe amounted circa eight billion euros in 2013. More parties active on the demand side of the rolling stock market has resulted in more second-hand transactions. To quickly increase transport capacity in times of increasing demand – supported by the time-consuming and costly certification process for new vehicles in other countries – rail operators increasingly eye second-hand vehicles. The respective sizes of the markets for new and used vehicles in 2013 are presented in Table 1.

TABLE 1: MARKET SIZE NEW AND USED RAIL VEHICLES

VEHICLE TYPE	NEW	SECOND-HAND
Multiple units and rail cars	900	80
High speed trains	50	- (unknown)
Passenger coaches	400	80
Locomotives	800	300
Freight wagons	10,000	- (unknown)
Source: Metz & Radstake (2013)		

Determined by means of straight-line depreciation, rail vehicle selling prices depend mainly on the book value and thus age. Mostly determined by an appraiser, a deviation factor is added to include technical characteristics and condition of the vehicle, under certain market conditions. Finally, the interaction between supply and demand determines the fair market value. This process may be costly and time-consuming for large and/or spread-out fleets, especially as railways are very capital intensive. Better estimation of vehicle values can reduce financial risks when making investment choices by reducing over- and under-pricing. Faster and more accurate valuation is also of interest for other involved parties, such as insurance companies and finance companies.

RESEARCH AIMS AND APPROACH

Within the rail industry, there is growing interest in more accurate, efficient and automated valuation approaches, based on market and rolling stock specific factors. Such approaches readily exist in ship and aircraft valuation, offering financial and efficiency benefits to vehicle owners, lessors, banks, investment funds, producers and insurance companies, and facilitating a dynamic and competitive vehicle market. Scientific theory identifies five broad explanatory factors influencing mobile asset value:

- *Sectors (groups of vehicles with sufficiently similar economics to be modelled together)*
- *Age*
- *Size*
- *Earnings (or a different market related factor)*
- *Technical features*.

This thesis aims to support this improvement in rail vehicle valuation by filling a scientific gap, as up until now scientific focus has been mainly on ships and aircraft, whilst this field of research has remained largely uncharted for rail vehicles. Therefore, the following main research question has been formulated:

1. *What are the main determinants of locomotive and freight wagon value; and*
2. *how does locomotive and freight wagon value depend on these factors economically and statistically?*

This twofold question comprises a qualitative and a quantitative part. In the former, academic and professional literature are reviewed to find suitable notions for the five broad explanatory factors for use in rail vehicle valuation, considering possible analogies with aircraft and ship valuation. Additionally, a number of explanatory factors specific to rail are identified and existing economic principles are established. Combined, it provides a framework for the use of statistical data analysis to support theoretical findings and to identify the dependence of rail vehicle value on the identified explanatory factors according to the framework model as visualized in Figure 1.

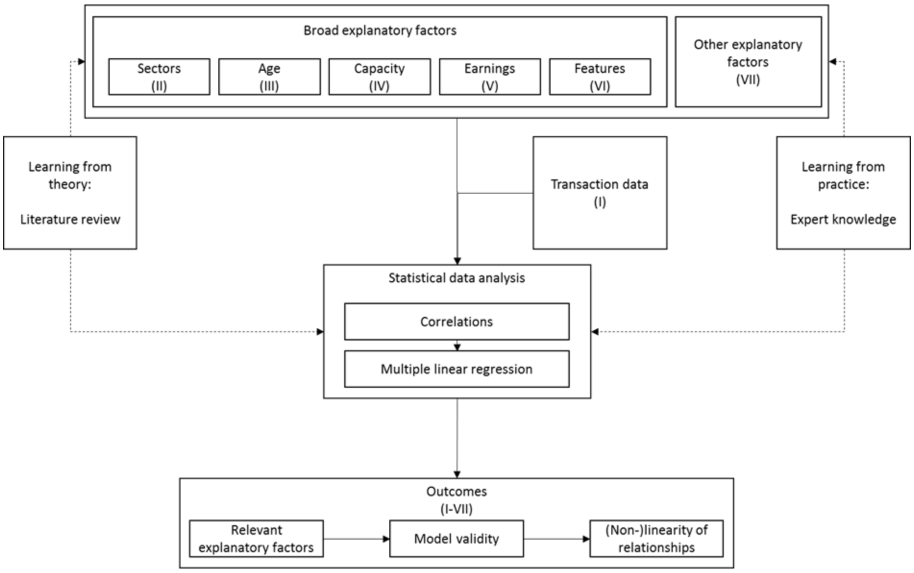

FIGURE 1: RESEARCH FRAMEWORK

In a first step of the quantitative part of this thesis, the aspects of data availability and quality are addressed. The viability of quantitative research builds on the availability of sufficient data to determine the relevance of possible determinants of rolling stock value validly. Data availability highly influences the scope of the research and the analysis possibilities. As such, this step functions as an input filter for the actual statistical data analysis.

Using multiple regression, the statistical data analysis employs a combination of the first statistical findings and theoretical knowledge. The advantage of this technique is the possibility to combine both quantitative and qualitative variables. By means of a theory-driven trial and error approach, a basic valuation model is extended systematically into more elaborate models. Here, the goal is to achieve parsimonious models to warrant high validity of the results.

Subsequent verification, (visual) evaluation and validation ensures that the outcomes are valid and generalizable. This diagnosis of the results aids in identifying if the assumption of linearity is indeed in place for the individual relations and the value function as a whole. Furthermore, it allows to draw conclusions about the dependence of locomotive and freight wagon value on these factors.

DETERMINANTS OF RAIL VEHICLE VALUE, THE RESULTS

Collected from a variety of sources, ranging from professional railway media, investment funds and online market places, 128 locomotive and 98 freight wagon transactions, closed between 2004 and 2016, were used for analysis.

SECTORS

Theoretically, locomotives are categorized in sectors by:

- function (e.g. mainline or shunting)
- propulsion (e.g. electric or diesel)

Quantitatively, the existence of sectors is supported, differentiating between mainline and shunting locomotives. Corrected for other variables, a positive sum is added for shunters, indicating their values are more stable over time. Theory and practice support the influence of the propulsion system of a locomotive on value, but this is not underpinned quantitatively.

Freight wagons are best grouped by cargo category. Using UIC freight wagon codes as sectors is not possible due to overlap in codes. Six cargo categories from shipping are defined to group wagons with similar economics with respect to technical and market factors:

- dry bulk
- liquid bulk
- intermodal
- break-bulk
- cars
- coils/plates

For freight wagons, the existence of sectors is quantitatively supported. Car transporters are found to be valued structurally higher than the values of other wagons, intermodal wagons slightly lower.

AGE

The relevance of age is underpinned theoretically and quantitatively in (mobile) asset valuation. Technical factors and the effects of supply and demand aside, age has an important share in a rail vehicle's selling price through its book value. Indications from practice rate that the influence of age on book value may be 70% of the final price, adding to its importance in rail vehicle valuation.

Quantitatively, age is one of the most relevant value determinants. Although the effect of age is considered linear in practice (mostly for convencience), both the locomotive and freight wagon valuation models reveal a non-linear relationship is more appropriate. This sees vehicle value decrease rapidly over time at first, but stabilizing for the highest vehicle values.

CAPACITY

No suitable indicator of capacity exists for locomotives, but multiple exist for freight wagons; both general and sector-specific. The general capacity in tonnes is used, as data availability prevents the inclusion of sector-specific indicators such as volume. Despite this compromise, the relevance of cargo capacity in relation to fair market value is supported. Corrected for other variables, the relationship is positive and linear. A higher capacity results in a better earning potential, allowing wagons to better compete in the market.

EARNINGS

Using similar notions of *Earnings* as used in ship or aircraft valuation is difficult due to the non-transparent nature of the rail market and inherent differences between the markets. Alternative notions suitable for modelling purposes are researched, to represent the influence of the market:

- The use of operating lease rates is problematic due to limited public availability and their static nature over time, as they are linked to the purchase price.

- The inclusion of order book sizes and/or the number of scrapped vehicles, as well as new building price levels and operational results, is recommended in theory, but impractical with respect to transparency, data availability and applicability.
- Assuming rail transport demand is linked to the demand for rail vehicles, the performance of the passenger rail and rail freight markets are practical alternatives, measured by the yearly number of passenger-kilometres and tonne-kilometres respectively.

Quantitatively, no significant influence on vehicle value is found. This is explained by the good performance of the rail market during the economic crisis of 2008. Vehicle purchases were hardly affected thanks to new passenger rail franchises and sufficient funds were available for investments. Thirdly, second-hand freight wagons traditionally find a new home quickly, keeping prices stabile.

TECHNICAL FEATURES

Theory underlines the importance of technical features as follows:

- features relate to vehicle efficiency and thus influence the ability to generate earnings
- features offer operational flexibility and influence resale potential
- features have a specific value of their own

Overall, they allow vehicles to compete in a market with vehicles with similar specifications. In practice, this is observed for old locomotives and wagons able to fulfil the same tasks as new ones.

Quantitatively, the main technical features found to be of influence on locomotive market value are:

1. **Primary power rating**
   The higher a locomotive's power rating, the higher its market value. Analysis shows it influences market value in a curvilinear way, adding value rapidly at first but stabilizing when power ratings increase to a high level due to the inclusion of a negative quadratic variable.
2. **Maximum speed**
   The maximum speed of a locomotive also influences its value in a non-linear fashion. Speed is included as a quadratic variable, adding value per every unit of speed slowly at first and increasingly fast for higher maximum speeds.

For freight wagons, no specific technical features are found to be of influence on market value. Of an extensive set of input variables, only tare weight is partly represented through a high multicollinearity with the general wagon capacity.

OTHER

Other determinants of rail vehicle value include:

1. **Manufacturer location**
   Ship valuation theory underpins differences between manufacturers from different countries. Due to data limitations, this thesis considers two groups: Western and Eastern European manufacturers. Analysis reveals that locomotives made by Eastern European manufactures are structurally valued lower. In the final locomotive model, they are penalized with an approximate €500,000 decrease in value. The variable is not found to be of influence on freight wagon value.
2. **The number of country approvals**
   About the number of country approvals, asset theory and rail valuation practice consider operational flexibility to increase resale potential and thus market value. In rail valuation, it is important due to the costly certification of second-hand vehicles in other countries. The number of country approvals is not analysed for freight wagons as all wagons in the dataset

have Europe-wide RIV / TEN approval. For locomotives, a quadratic increase in market value is found for every additional country authorization, ceteris paribus.

3. **If a vehicle is in a valid maintenance regime.**
   Practice shows that when a main overhaul or additional maintenance is required, vehicles are valued lower due to the high extra costs involved for the potential buyer. Analytically, the data does not support its influence on locomotive value. In the freight wagon valuation model, wagon value is decreased by circa €16,000 when not in a valid regime.

CONCLUSIONS AND RECOMMENDATIONS

Table 2 lists the relevant factors for both vehicle types. By taking lessons from both theory and practice, this thesis succeeds in identifying several main determinants of vehicle value, according to the broad factors *Sectors*, *Age*, *Capacity* and *Technical features*. However, it fails to identify a suitable and quantitatively supported notion of *Earnings*.

TABLE 2: OVERVIEW OF RELEVANT VALUE DETERMINANTS

	SECTORS	**AGE**	**CAPACITY**	**EARNINGS**	**FEATURES**	**OTHER**
LOCOMOTIVES	*Sector shunter*	*Age, Age^2*	n/a	-	*Power rating primary*	*Number of country approvals^2*
					Power rating primary^2	*Manufacturer Eastern Europe*
					Speed^2	
	SECTORS	**AGE**	**CAPACITY**	**EARNINGS**	**FEATURES**	**OTHER**
FREIGHT WAGONS	*Sector intermodal*	*Age, Age^2*	*General capacity*	-	-	*No revision*
	Sector cars					

The full model results and corresponding regression equations are presented in Table 3 and Table 4, Equation 1 and Equation 2. The locomotive and freight wagon models are able to explain of 88.9% and 78.4% of the variance in vehicle value respectively, at a 0.05 significance level. The remaining variance is attributed to the state of the vehicle, of which the determination includes some extent of subjectivity, and any potential (external) determinants that could not be included

TABLE 3: LOCOMOTIVE VALUATION MODEL

LOCOMOTIVES (ADJ. R^2 = 88.9%, α = 0.05)									
	Unstandardized coefficients		**Stand. coefficients**			**95% Confidence interval for B**		**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Lower bound**	**Upper bound**	**Tolerance**	**VIF**
Constant	523,117	193,930		2.697	.008	139,116	907,117		
Age	-86,385	7,927	-1.312	-10.897	.000	-102,082	-70,689	.060	16.561
Age^2	1,042	148	.876	7.042	.000	749	1,334	.057	17.661
Power rating primary	1,128	131	1.637	8.626	.000	869	1,387	.024	41.157
Power rating primary^2	-.123	.018	-1.206	-7.023	.000	-.158	-.089	.030	33.694
Speed^2	18	6.9	.135	2.594	.011	4	32	.321	3.111
Number of country approvals^2	32,890	7.340	.161	4.481	0.00	18,356	47,423	.674	1.483
Manufacturer Eastern Europe	-508,111	113,019	-.139	-4.496	.000	-731,900	-284,322	.911	1.098
Sector shunter	591,311	165,405	.171	3.575	.001	263,793	918,830	.384	2.606

$$\begin{aligned} Value\ (€) = \; & -523{,}117 + (-86{,}385 * Age) + (-1{,}042 * Age^2) + \left(1{,}128 * Power_{primary}\right) \\ & + \left(-.123 * Power_{primary}{}^2\right) + (18 * Speed^2) + \left(32{,}890 * No_{country\ approvals}{}^2\right) \\ & + (-508{,}111 * Man_{east}) + (591{,}311 * Sector_{shunt}) + \ \varepsilon \end{aligned}$$

EQUATION 1: VALUE FUNCTION – LOCOMOTIVES

The advantage of a semi-parametric approach is shown: several non-quantitative variables influence vehicle value. It is impossible to cover all aspects of rail valuation with mere quantitative models.

TABLE 4: FREIGHT WAGON VALUATION MODEL

FREIGHT WAGONS (ADJ. R^2 = 78.4%, α = 0.05)									
	Unstandardized coefficients		Stand. coefficients			95% Confidence interval for B		Collinearity statistics	
	B	Std. Error	β	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
Constant	32,017	11,623		2.755	.007	8,930	55,104		
Age	-2,381	447	-.916	-5.324	.000	-3,269	-1,492	.075	13.311
Age²	36	9.596	.603	3.704	.000	16	55	.084	11.891
Capacity general	.792	.161	.329	4.911	.000	.471	1.112	.496	2.018
No revision	-16,361	6033	-.148	-2.712	.008	-28,345	-4,378	.747	1.339
Sector cars	168,785	16,153	.518	10.449	.000	136,700	200,871	.907	1.102
Sector intermodal	-12,425	5.837	-1.07	-2.128	.036	-24,020	-829	.888	1.126

$$Value\ (€) = 32{,}017 + (-2{,}381 * Age) + (36 * Age^2) + \left(.729 * Cap_{general}\right) + (-16{,}361 * Rev_{no}) + (168{,}785 * Sector_{cars}) + (-12{,}425 * Sector_{intermodal}) + \varepsilon$$

EQUATION 2: VALUE FUNCTION - FREIGHT WAGONS

The largest limitation of this research is data availability, as it does not allow for the estimation of more elaborate models without affecting the generalizability of the results and thus validity. A parsimonious approach is followed, as model validity is considered more important than model size. Another limitation is the lack of operational aspects. Theory emphasizes their importance, as vehicle value depends on the ability to generate earnings for the owner too. Also, the model only includes supply side variables to determine fair market value, but no demand side (e.g. state of the passenger and rail freight markets). Lastly, it considers fixed vehicle specifications during its lifetime, while increasing modularity allows easier upgrades of vehicle properties such as speed. This may change the way value is attributed to certain attributes in the future.

For further research, the main advice is to opt for a semi-parametric technique again. The five broad explanatory factors that play a central role in this research, but also in aircraft and ship valuation, should be covered. Additionally, it should be included whether a vehicle is in a valid maintenance regime or not. These requirements exclude the use of parametric techniques other than to use them in a confirmatory way to underpin the relevance of the found quantitative variables. An expansion of this research is proposed by using general additive models to include non-linear effects between explanatory variables and value, whilst maintaining a similar value function.

A second option for future research is a net present value technique, similar to Vasigh & Erfani (2004), to further underpin the relevance of the most important explanatory variables. Such a research can also be performed using the five broad explanatory factors: a great benefit. Additionally, it would be able to overcome the lack of activity related factors such as increasing operational costs through the years. However, the data dependency of such a technique is much higher, so it should only be pursued when data availability is ensured.

High data availability may also open doors for data mining of transaction records, which could be promising for internal research within railway finance organisations/brokers with large rolling stock transaction databases. It requires sufficiently sized datasets to be able to identify patterns. As for multivariate analysis, data quality is of great importance and excluding records with noise or missing data is required. Using a clean dataset, data mining allows to detect outliers and unusual records, but also to discover groups and to create regression functions to find relationships.

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LIST OF ABBREVIATIONS

AAR:	Association of American Railroads
AC:	Asynchronous Current
ACTS:	Afzet Container Transport Systeem or Abrollcontainer Transportsystem
ATB EG:	Automatische Treinbeïnvloeding Eerste Generatie
ATB NG:	Automatische Treinbeïnvloeding Nieuwe Generatie
CIS:	Commonwealth of Independent States
DB:	Deutsche Bahn
DC:	Direct Current
De:	Diesel-electric
Dh:	Diesel-hydraulic
Dm:	Diesel-mechanic
ERTMS:	European Rail Traffic Management System
ETCS:	European Train Control System
EVN:	European Vehicle Number
FS:	Ferrovie dello Stato
GSM-R:	Global System for Mobile Communications - Railway or GSM - Railway
ISO:	International Organization for Standardization
HU:	Hauptuntersuchung or main overhaul
LEU:	Lineside electronic unit
lu:	Useful length of a freight wagon in metres
LZB:	Linienförmige Zugbeeinflussung
MS:	Multisystem
NMBS:	Nationale Maatschappij der Belgische Spoorwegen
NS:	Nederlandse Spoorwegen
ÖBB:	Österreichische Bundesbahnen
pa-(container):	Porteur amenáger container or ‘von-Haus-zu-Haus container’
PGW:	Prawila polsowanija grusowymi wagonami w meshdunarodnom soobshenii or Rules of Reciprocal Use of Wagons in International Traffic
PZB:	Punktförmige Zugbeeinflussung,
RIV:	Regolamento Internazionale Veicoli or International Wagon Regulations
SCMT:	Sistema di Controllo della Marcia del Treno
SNCF:	Société Nationale des Chemins de fer Français
TEN:	Trans-European Network
TEU:	Twenty-foot Equivalent Unit
tu:	Maximum permissible load of a freight wagon in tonnes
TSI:	Technical Specifications for Interoperability
TSI LOC&PAS:	Technical Specifications for Interoperability relating to the ‘rolling stock - locomotives and passenger rolling stock’ subsystem of the rail system in the European Union
TSI WAG:	Technical Specifications for Interoperability relating to the ‘rolling stock - freight wagons’ subsystem of the rail system in the European Union
UIC:	Union Internationale des Chemins de Fer or International Union of Railways

1: INTRODUCTION

“By implementing concepts that have proven their worth in other industries, we can boost our products, our performance, the quality of our service, and the overall-quality of the rail industry.”

Geert Pauwels, CEO, B Logistics

(Pauwels, 2016)

1.1 THE MARKET

The market for rail vehicles is becoming increasingly dynamic and global. An important driver of this development is the liberalisation of the market for passenger and freight rail transport in Europe (Nieuwenhuis, 2012). Originally, national players, predominantly serving their home market, dominated the European rail transport market. Technically, almost each European country had developed its own railway system, resulting in differences in track gauge, clearance profile, overhead power supply systems and train protection systems. Similarly, almost every country had its own domestic rolling stock suppliers and rolling stock series, creating a segmented rolling stock market.

In the early nineteen-nineties, the European rail market started to reform thanks to efforts of the European Economic Community. With the implementation of Directive 91/440/EEC, the European Economic Community aimed to increase the efficiency and competitiveness of the rail transport market by a separation of the entities responsible for rail transport on the one hand and those responsible for infrastructure management on the other hand (European Economic Community, 1991). This Directive has been superseded by the First Railway Package in 2001, the Second Railway Package in 2004 and the Third Railway Package in 2007. A Fourth Railway Package was introduced by the European Commission in 2013 and approved for implementation in 2016. DeHousse and Marsicola (2015) describe that EU railway policy focuses on three main areas required for a strong and competitive railway industry, namely:

- introducing competition by creating an open market on a European level
- improving interoperability and safety of railway networks in the member states
- developing the required transport infrastructure to support the above

Simultaneously, globalisation of trade requires railways to operate more internationally. The European Commission supported this on an infrastructure level by setting standards with respect to track gauge (1435mm), train protection systems (ERTMS) and overhead power (25kV). The rolling stock industry focused on interoperability by developing vehicles able to cope with the technical differences between countries and the newly introduced European standards.

Because of a policy of liberalisation of the railway market and globalisation of trade, also the European rolling stock industry itself changed. On the supply side, the market started to consolidate, resulting in fewer but larger rolling stock producers that not only operate on a European level (Shift2Rail, 2016), but now also compete on a global level (SCI Verkehr, 2014). Therefore, the rolling stock market characterises itself as oligopolistic. According to SCI Verkehr (2014), the twenty largest manufacturers of rail vehicles covered 85% of the market in 2012.

Furthermore, lead times for new rolling stock are relatively long. Especially for self-powered vehicles, the time between order and delivery may amount several years. However, there are more and more examples of manufacturers producing vehicles on stock in anticipation of orders, such as Vossloh

Locomotives with its G 6 diesel shunter and Siemens with its electric Vectron locomotives. This enables considerably shorter lead times, ranging from weeks to months.

Through the years, manufacturers active in the European market rationalized their product portfolios towards more standardized product families suitable for different countries. Examples are Siemens with its EuroSprinter (Siemens, 2016a) and Vectron locomotives (Siemens, 2016b), Bombardier Transportation with its TRAXX locomotive family (Bombardier Transportation, 2016b) and Stadler Rail with its GTW (Stadler Rail, 2016d) and FLIRT multiple unit families (Stadler Rail, 2016c) that are in operation in many European and non-European countries. This trend mainly applies to powered vehicles, as non-powered rail vehicles face less technical barriers for international operations.

A large part of the European freight and passenger wagon fleet already operates under standardization agreements in use since the early nineteen-twenties. In 1921, the Regolamento Internazionale dei Veicoli (RIV) agreement came into force, governing the interoperability of freight and passenger wagons with a focus on Western and Central Europe. In January 2007, TEN replaced RIV according to Technical Specifications for Interoperability for freight wagons (TSI-WAG) (DB Schenker Rail AG, 2011). Regolamento Internazionale delle Carrozze (RIC), a similar agreement for passenger wagons, had been in use since 1922. This agreement between various European countries sets out technical requirements for interoperable use of passenger wagons and covers certain operational and commercial aspects. Although RIC is still recognized to a certain extent, TSI legislation supersedes it in a similar way as for freight wagons (European Railway Agency, 2009). Analogous to locomotives and multiple units, interoperability requirements for passenger wagons are stipulated in TSI LOC&PAS (European Commission, 2014).

Thanks to the liberalisation of the European railway market and the increasing interoperability of rail vehicles, the barriers for private passenger and freight operators to enter this market disappeared, increasing the number of active players. Furthermore, the creation of leasing companies, often backed by financial institutions such as banks, allowed to separate ownership and use of rolling stock, which was already common practice for freight wagons. The shares of leasing companies in new vehicle deliveries illustrate this (Table 5). The effects of liberalisation become clear when taking the distribution of multiple unit deliveries between (former) state-owned and private operators into account. Metz & Radstake indicate that 39% of all new multiple units were delivered to private operators in 2012.

TABLE 5: SHARE OF LEASING COMPANIES IN NEW RAIL VEHICLE DELIVERIES IN 2013

VEHICLE TYPE	SHARE
Multiple units and railcars	20%
Locomotives	33%
Freight wagons	66%
Source: Metz & Radstake (2013)	

The possibility to separate ownership and use of rail vehicles facilitated the entry of new rail freight operators to the railway market. It enabled them to pay for new vehicles on a monthly basis with the monthly revenues earned from transport contracts instead of paying a large sum prior to delivery of the vehicle (Mitsui Rail Capital Europe, 2011). Whereas the often-large (former) state railways and leasing companies are responsible for most of the direct purchases of new rolling stock, new private market players mostly rely on leased and/or second-hand stock for their train operations. There are examples of leasing companies acquiring used vehicles, but this mostly concerns sale-and-leaseback constructions or deals between leasing companies.

Nonetheless, the market for new vehicles is large. According to DVB Bank (Metz & Radstake, 2013), the total yearly investment in new rail vehicles in Europe amounts an approximate eight billion euros, divided over:

- 900 multiple units and rail cars
- 50 high speed trains
- 400 passenger coaches
- 800 locomotives
- 10,000 freight wagons

With more parties active on the demand side of the market, the number of second-hand transactions increases too, especially when leasing companies and (former) state railways renew their fleets. Furthermore, Metz & Radstake (2013) identify that in times of increasing demand for rail transportation (e.g. after the economic crisis of 2008 during which investments in new vehicles hit a low), there is an increased demand for used vehicles. Additionally, they identify an important driver of the second-hand market in the growing problem to source new vehicles that are already certified for use in other countries. As the certification costs can amount €2 to €4 million per country and the process may take two to four years to complete, certification of new long-distance vehicles costing between €2.5 and €4.5 million is relatively expensive.

When it concerns a used vehicle specifically developed for operations in one or just a few countries, this process may be even more costly. However, even with the introduction of European technical specifications as TSI Loc & Pas, which are meant to decrease certification costs of new vehicles, Metz & Radstake note that it may still be worthwhile to approve second-hand vehicles for new countries due to the ever-increasing prices of new rolling stock. With respect to the size of the second-hand market (i.e. for vehicles older than thirteen years), they indicate that an approximate 300 locomotives, 80 passenger wagons and 80 multiple units switch owners every year. No numbers are given for the number of freight wagons traded on the second-hand market every year.

1.2 RAIL VEHICLE APPRAISAL

Determining the selling price of a rail vehicle can be a straightforward process for new rolling stock by taking the price off-factory, but for used vehicles, it is less easy. Current common practice in rail valuation is that the book value is taken as a starting point and that the final selling price is estimated by the expert judgement of an appraiser that visits the vehicle on site. The resulting fair market value is the subsequent result of the effects of supply and demand. The appraiser not only examines the general state of the vehicle, but also considers technical characteristics when determining the value of a vehicle under certain market conditions. This appraisal process is mainly based on the experience of the appraiser, keeping in mind historical value determinations and transactions. When rolling stock fleets are large and/or located at different locations in Europe, this process may be costly and inefficient.

However, there is a need within the market to develop more automated and digital approaches to rolling stock valuation to enable more rapid and in-depth economic and financial analysis. To enable the use of such approaches in the rail rolling stock market, insight is needed in the relations between market and rolling stock specific factors on the one hand and market value on the other. With those relations known, the expected fair market value of rail vehicles (i.e. the expected selling price in a transaction between a willing buyer and willing seller) could be estimated with a proverbial push on the button. Contrary to the rail vehicle market, automated valuation techniques are readily available in the aircraft and ship markets. Furthermore, the focus of supporting scientific theory has also been on these markets, whilst rail vehicle valuation remains largely uncharted area. Nevertheless, there is an underlying principle that many valuation approaches have in common, namely that the value of an asset depends on both market conditions and technical characteristics.

ASCEND Flightglobal Consultancy (2014) considers *“the value of an aircraft can best achieve under today’s open market conditions”* and *“takes into account age and specification of the asset in order to determine the Current Market and Base Values”*. International Bureau of Aviation (IBA) uses a similar principle to predict value by using market data and correcting this for specific aircraft specifications so that it *“not just reflects a ‘text book’ example”* (IBA Group, 2016). IBA further describes these specifications as *“Measurable Effects”* and gives examples such as engine model and winglets (IBA Group, 2014). In their paper *Aircraft Valuation in Dynamic Air Transport Industry* (Gorjidooz & Vasigh, 2010), Gorjidooz and Vasigh state that *“Factors determining an aircraft’s value not only include the physical characteristics of the aircraft, such as size, age, seat capacity, fuel efficiency, and physical condition, but also include maintenance status and maintenance documentation; operating expenses and revenue; demand and its elasticity; inflation rates and interest rates; fuel cost; safety issues and regulation; and finally, environmental regulations”*.

For ships, Koehn showed in his Ph.D. Thesis ‘Generalized Additive Models in the Context of Shipping Economics’ (2008) that technical characteristics of vessels are of influence on their second-hand prices. Previous work by Adland & Koekebakker (2007) only included size and age of the ship, as well as *“the state of the relevant freight market”*, but showed that both technical and market factors are of influence. A Harvard Business School case by Esty and Sheen (2010) not only considers the findings of Adland & Koekebakker (2007), but also shows that value estimation can be done by comparing the value of ships with similar technical features, adding to the importance of technical features. Others illustrating the influence of the state of the shipping market on the value of vessels include Beenstock (1985), Haralambides et al. (2005) and Puyn et al. (2011). VesselsValue uses market data and ship-specific technical specifications to estimate the fair market value of vessels. Five broad explanatory factors of both a technical and financial nature are found to be of influence on the fair market value namely: *Sector*, *Age*, *Size*, *Earnings* and *Features* (Adamou, 2011).

Differences between the markets for rail vehicles, aircraft and ships mean that these factors will not necessarily apply directly to rail vehicles. Some factors may be less relevant, while other factors, which do not apply to ships or aircraft, may be important in rail. In other words, the economic principles of valuation may not be the same in the rolling stock market as they are in the shipping or the aircraft market. Therefore, these principles must be researched and established, and the relevant factors identified and characterised, cf. chapter 4 of Koehn (2008) for product tankers. Possible analogies between the three markets serve as a starting point, using factors that previous research in aircraft and ship valuation have in common and that may exist for rail vehicles too:

- *Sectors*
- *Age*
- *Capacity/size*
- *Earnings/revenues*
- *Technical characteristics/features*

In the remainder of this document, *capacity/size* will be referred to as *Capacity*, *Earnings/revenues* as *Earnings* and *Technical characteristics/features* as *(Technical) features*.

1.3 SCIENTIFIC AND PRACTICAL GOALS

The outcomes of this research are both of theoretical and practical importance. From a theoretical perspective it provides insight in how rolling stock value depends on both technical factors and general market conditions. In science, there is a substantial interest for the relationship between the value of (mobile) capital assets on the one hand and technological and economic factors on the other hand. As scientific focus has been mainly on ship and aircraft valuation, the field of rail vehicle valuation remains largely unexplored. By venturing into this largely uncharted research area, this thesis aims to lay the basis for rail vehicles as another pillar in the field of transport vehicle valuation. Furthermore, this research implicitly addresses the question whether multiple regression is adequate to determine the value of rail vehicles based on a set of explanatory factors.

From a practical perspective, it aims to provide a scientific basis for the creation of rail vehicle valuation models that enable better desktop valuation for all parties involved in vehicle transactions. The benefits of this are twofold and comprise:

- **Financial benefits**
  These are created when models building on the knowledge gathered in this research reduce the need for an appraiser. Especially for large rolling stock fleets spread over several countries, hiring an appraiser is costly and time-consuming. Furthermore, the railway system is capital intensive. Nieuwenhuis (2012) indicates that the costs of traction (i.e. lease, ownership and maintenance) can be as high as 25% of the total costs for a rail freight operator. For freight wagons, this can be as high as 18%. Better vehicle value estimation can considerably reduce financial risks when making investment choices by reducing the chance that a buyer pays too much or a seller receives too little for a rail vehicle. Buyers and sellers may be railway operators, leasing companies, banks, investment funds and manufacturers.
- **Efficiency benefits**
  These are created when such a rail valuation model is able to considerably shorten such a time-consuming valuation process. Other parties in the rolling stock market may also obtain benefits, as remarketing vehicles can become less costly and time-consuming for all parties involved in a second-hand transaction. In turn, benefits may arise for insurance companies, who use the estimated value of rail vehicles to determine insurance fees and conditions, and financial institutions that provide financing solutions for the acquisition of rolling stock.

1.4 RESEARCH QUESTIONS

The need for more automated and digital approaches to rail vehicle valuation, enabling more rapid and in-depth economic and financial analysis, requires insight in the influence of market and technical factors on market value. This thesis aims to support this improvement in rail vehicle valuation by filling a scientific gap, as up until now scientific focus has been predominantly on ship and aircraft valuation. In contrast, this field of research has remained largely unexplored for rail vehicles. Therefore, the following twofold main research question is formulated:

1. *What are the main determinants of locomotive and freight wagon value; and*
2. *how does locomotive and freight wagon value depend on these factors economically and statistically?*

Considering the five broad explanatory factors in Section 1.2 and the main research question, seven sub questions are formulated. These can be grouped in two categories, covering the transaction data (I) and the identified broad explanatory factors (II-VII), of which the latter are analysed jointly.

I. *How frequent are sale and purchase transactions for rail rolling stock? Is the size of the market sufficiently large and does it provide sufficiently available data of a satisfactory quality for a reliable application of more automated valuation techniques?*

Statistical analysis requires sufficient data to give it explanatory and/or predictive power, both in theory and practice. The frequency of sale and purchase transactions for rail vehicles and the quality of available data determines the usability of more automated valuation approaches in this market.

II. *Do 'Sectors' exist in rail? If so, how should they be defined?*

Sectors are groupings of vehicles whose economics are sufficiently similar to be modelled together. In shipping, they are identified by ship types (e.g. VLCC and Suezmax) carrying similar cargos on similar routes, such that their economic performance is related. The question is how sectors in rail should be defined according to theory and to what extent their existence is quantitatively supported.

III. *How does the ´Age' of rail vehicles influence their market value?*

Similar to other capital assets, the value of rail vehicles depreciates over time. The question is how depreciation is calculated in practice and what the depreciation profile looks like.

IV. *How should the factor 'Capacity' be defined in rail valuation? And if defined, how does it influence the market value of rolling stock?*

In shipping, capacity is defined as the cargo capacity of a vessel. In rail, this factor is not applicable to all vehicle types. A suitable notion of *Capacity* should be defined, in general or per sector.

V. *Is there a notion of 'Earnings' relevant to rolling stock values? If so, what? And, how is it of influence on the market value of rail vehicles?*

Earnings in the rail market differ from those in shipping and air transport, but may be of influence on value. Whether and how these influence vehicle value should be researched more thoroughly.

VI. *What 'Features' (i.e. technical specifications and equipment) of rail vehicles are relevant determinants of market value and how do they influence it?*

Because rail rolling stock includes both freight and passenger vehicles, the differentiation in types is large. Therefore, rolling stock specifications also differ greatly. Analogous to the shipping market, it is expected that features will have an effect on the value of a rail vehicle. Examples could be the presence of ETCS or other train protection systems, maximum power rating and emission levels.

VII. *Are there any other determinants of value (specific to the rail market)? And, in what way do those determinants influence value?*

Other aspects, specific to rail vehicles, may influence value. For example, manufacturer reputation or the position in a maintenance regime may cause value differences between similar vehicles.

1.5 PRELIMINARY CONCEPTUAL MODEL

The preliminary conceptual model (see Figure 2) assumes two variable groups that influence vehicle value, namely the broad explanatory factors found in vehicle valuation theory and possible other rail-specific explanatory variables. The broad factors are *Sectors*, *Age*, *Capacity*, *Earnings* and *Features*. Per researched vehicle type, these are to be made more explicit by determining specific factors.

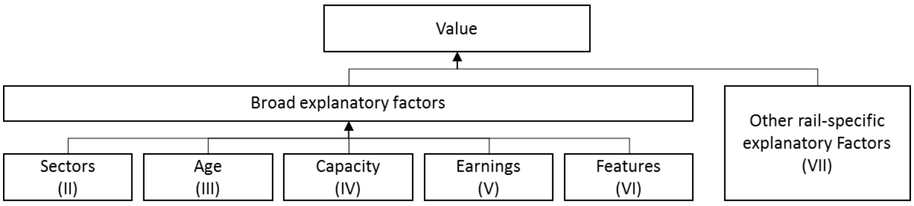

FIGURE 2: PRELIMINARY CONCEPTUAL MODEL

1.6 THE CHOICE FOR MULTIVARIATE ANALYSIS

A multivariate analysis technique is chosen over a bivariate technique, as it can take into account multiple measurements on the considered vehicles simultaneously. Simply said: whereas bivariate techniques can only cover the influence of one independent variable on the dependent variable, multivariate techniques enable the researcher to consider combinations of two or more independent variables at the same time and to find more complex relations with the dependent variable. The suitability of multivariate modelling for rail vehicle valuation lies in the fact that value, the dependent variable, is measured on a continuous scale and multiple independent factors are present.

The use of multivariate modelling in value determination is less established than the use of accounting methods. Nevertheless, as Koehn (2008) showed, valuation models that can take into account generic market variables and technical features are potentially very useful for all actors involved. Pruyn et al. (2011) underline this in their review of valuation methods, noting the shortcoming of traditional methods in being unable to include such a wide range of variables.

1.7 STRUCTURE OF THE RESEARCH

The research project can be divided into two main parts, according to the main research question in Section 1.3. The first part is of a qualitative nature. It is to identify, by means of literature review and analysis of rail market and vehicle/fleet data, the main determinants of rolling stock value, provide a foundation for the quantitative part of this thesis. This quantitative part is to describe – in both economic and statistical terms – the dependence of value on these factors where possible.

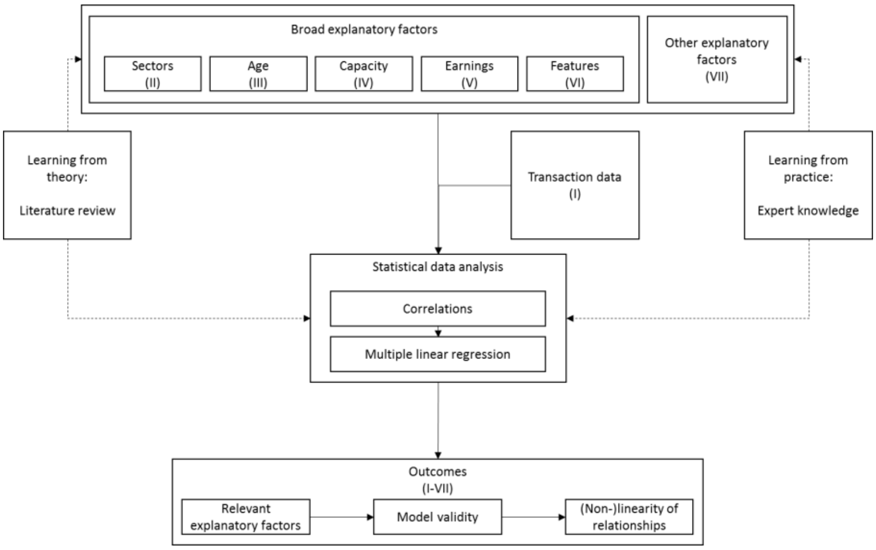

FIGURE 3: RESEARCH FRAMEWORK

Figure 3 presents the structure of this thesis. First, insight is gained in rail vehicle valuation – and (mobile) asset valuation in general – through a combination of established theory and knowledge from practice. This theoretical and practical basis enables the selection of a set of possible, more specific, explanatory factors that cover technical, market and other aspects. Upon completion of this qualitative part, it is not only possible to make a step forward to the quantitative part using the theoretical basis, possible explanatory factors and the corresponding transaction data as input. Also, it is to answer the quantitative aspects of the research questions specified in the previous section.

The quantitative part of this research commences by addressing the availability of transaction data to determine the correct scope of the research (i.e. research question I). As the title indicates, this results in a focus on locomotives and freight wagons. By means of statistical data analysis, the quantitative part of this research then continues with a number of descriptive statistics and the correlations between the variables. This gives some first hints about the relations between the explanatory factors and provides starting points for further analysis.

Subsequently, separate models for locomotives and freight wagons are set up systematically, using multiple regression in a theory-driven approach. Thereby, insight is gained in the explanatory factors relevant to rail vehicle value, their respective importance and possible interdependencies. As such, multiple regression is used in an explanatory way. In a more predictive application, the objective is to maximize the predictive power of the models with the found explanatory variables. Evaluation of the results and diagnosis techniques for multiple regression aid in ensuring model validity. Determining the confidence intervals is to aid in defining the uncertainty in the estimations.

1.8 STRUCTURE OF THE REPORT

A review of academic and professional literature is performed in Chapter 2 to identify previous work in this area and to establish the existing theory behind the valuation of aircraft, ships, capital assets in general and rail vehicles specifically, considering the broad explanatory factors identified in Section 1.3. Together with a first analysis of transaction data, specific explanatory variables for rail vehicles are identified that are to be used as input for the quantitative analysis.

Research question I – *How frequent are sale and purchase transactions for rail rolling stock? How can we draw robust conclusions about the relevance of factors if transaction data are sparse?* – is an essential question in this research. The viability of this thesis builds on data availability to determine the relevance of value determinants and greatly influences the scope of the research. However, even if sufficient data is available, the quality of the collected data determines its usability. Chapter 3 gives insight in the collection, the availability and the quality of the available data.

Starting in Chapter 3, the quantitative part of this thesis comprises of three main steps. The first part focuses on the input for the multivariate analysis that takes places in the second step. Firstly, the collected data is subjected to a missing value analysis and, where needed, to a first transformation to achieve a dataset with variables and variable values suitable for further statistical analyses. Then, the data is subjected to a first examination by means of descriptive statistical techniques.

In Chapter 4, the second quantitative step is introduced: data analysis in the form of linear multiple regression. Based on a combination of the first statistical findings (i.e. correlations) and the theoretical knowledge established in the qualitative part of this research, a basic model is set up that is extended systematically into more elaborate models by means of a theory-driven trial and error approach. Subsequently, the resulting models are compared with models produced through an automated approach, which includes only the strongest relationships, to achieve parsimony.

Chapter 5 repeats the steps taken in Chapters 4 and 5 with the inclusion of non-linear variables to reveal whether full linear multiple regression is appropriate or not. The outcome of this chapter comprises of the final valuation models, concluding the quantitative part of the thesis.

Chapter 6 concludes this thesis by first linking the outcomes of both the qualitative and quantitative parts of this research to the research questions set out beforehand. Subsequently, it briefly summarizes the validity of the results and if the outcomes are in line with expectations. It continues by addressing the limitations of the research. Lastly, recommendations for future research are presented to the reader.

2: LITERATURE REVIEW

> *“Fahrzeuge erreichen den höchsten Restwert, wenn sie: gut gewartet, für viele Länder zertifiziert, Teil einer größeren Flotte und vergleichsweise modern mit Blick auf Neufahrzeuge sind, und von vielen Eisenbahn- und Leasingunternehmen benutzt oder im Eigentum stehen“*
>
> *Martin Metz, Global Head Land Transport Finance, DVB Bank*
> *Wouter Radstake, Senior Vice President Land Transport, DVB Bank*
>
> *(Metz & Radstake, 2013)*

This chapter combines academic and professional literature to form a theoretical base for the quantitative assessment of rolling stock values and possible determinants. Different forms of asset valuation are considered and analogies with aircraft and ship valuation are sought. Then, the possible existence of sectors in rail is researched, followed by a description of various depreciation methods. Subsequently, the influence of capacity on value is researched. In a next step, a concept of earnings, suitable for quantitative analysis, is established for rail vehicles. Lastly, the importance of technical features is considered.

The approach followed in finding relevant high-quality literature is a mix of searching for articles, papers and publications directly with related key words and using the references of found literature to find further work of others. The latter, also known as snowballing, has the intrinsic risk of ignoring different approaches and views to asset valuation. To maintain a broad view of the advantages and disadvantages of all valuation techniques and assumptions, it was not the sole search approach used.

2.1 THE DEFINITION OF VALUE

First, the concept of value requires clarification, as several definitions exist. Firstly, there is perceived value, which has personal and social aspects. Woo (1992) distinguishes four forms:

- *“what is of true worth to people in the broad context of the well-being and survival of individuals, and by extension, of the species as a whole”*
- *“what a society collectively sees as important…regardless of whether or not such highly valued objects of consumption really contribute to his or her well-being”*
- *“what the individual holds to be worthwhile to possess, to strive or exchange for”*
- *“the amount of utility that consumers see as residing in a particular object and they aim to maximize out of a particular act of buying or consuming”*

Of the four definitions, the first three are mostly related to personal and societal human values. The fourth definition considers the economic theory of utility maximization. Even though the economic aspect of this definition is most apparent, it does not match the concept of value in this thesis.

There also is the concept of book value, which is traditionally used in accounting and which represents the value of an asset on the balance of its owner. It is calculated by reducing the cost of the asset with the accumulated depreciation charges at a specific point in time. However, the book value is not necessarily equal to the price at which a vehicle exchanges owners, but plays an important role.

A more accurate definition is sought in asset appraisal. The Machinery & Technical Specialties Committee of the American Society of Appraisers (2010) uses the following definitions:

- **Reproduction Cost New**
  "The cost of reproducing a new replica of a property on the basis of current prices with the same or closely similar materials, as of a specific date."
- **Replacement Cost New**
  "The current cost of a similar new property having the nearest equivalent utility as the property being appraised, as of a specific date."
- **Fair Market Value**
  "An opinion expressed in terms of money, at which the property would change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or to sell and both having reasonable knowledge of relevant facts, as of a specific date."
- **Fair Market Value in Continued Use with Assumed Earnings**
  "An opinion, expressed in terms of money, at which the property would change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or to sell and both having reasonable knowledge of relevant facts, as of a specific date and assuming that the business earnings support the value reported, without verification."
- **Fair Market Value in Continued Use with an Earnings Analysis**
  "An opinion, expressed in terms of money, at which the property would change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or to sell and both having reasonable knowledge of relevant facts, as of a specific date and supported by the earnings of the business."
- **Fair Market Value – Installed**
  "An opinion, expressed in terms of money, at which the property would change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or to sell and both having reasonable knowledge of relevant facts, considering market conditions for the asset being valued, independent of earnings generated by the business in which the property is or will be installed, as of a specific date."
- **Fair Market Value – Removed**
  "An opinion, expressed in terms of money, at which the property would change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or to sell and both having reasonable knowledge of relevant facts, considering removal of the property to another location, as of a specific date."
- **Liquidation Value in Place**
  "An opinion of the gross amount, expressed in terms of money that typically could be realized from a properly advertised transaction, with the seller being compelled to sell, as of a specific date, for a failed, non-operating facility, assuming that the entire facility is sold intact."
- **Orderly Liquidation Value**
  "An opinion of the gross amount, expressed in terms of money, that typically could be realized from a liquidation sale, given a reasonable period of time to find a purchaser (or purchasers), with the seller being compelled to sell on an as-is, where-is basis, as of a specific date."
- **Forced Liquidation Value**
  "An opinion of the gross amount, expressed in terms of money, that typically could be realized from a properly advertised and conducted public auction, with the seller being compelled to sell with a sense of immediacy on an as-is, where-is basis, as of a specific date."

- **Salvage Value**
  "An opinion of the amount, expressed in terms of money that may be expected for the whole property or a component of the whole property that is retired from service for possible use elsewhere, as of a specific date."
- **Scrap Value**
  "An opinion of the amount, expressed in terms of money that could be realized for the property if it were sold for its material content, not for a productive use, as of a specific date."

The above illustrates the necessity of a clear definition of value. When discussing value in this thesis, the Fair Market Value is meant for two reasons. Firstly, transaction data is analysed that contains information about the price as established when the asset changed *"hands between a willing buyer and a willing seller"*, reducing the number of possible definitions to five. Secondly, the assumption is made that the value of a vehicle is established under normal conditions. This implies that the general state of the asset is normal for its age, whether in a valid maintenance regime or not, so there is no need to salvage or scrap the vehicle. Furthermore, the conditions under which the transactions took place are considered normal. This means that the deal has been closed in a market environment where buyer and seller come together without special circumstances, such as forced liquidation. The value of a vehicle sold under extraordinary circumstances may easily be an under- or overestimate of the fair market value at the time of appraisal.

Five definitions remain possible, namely the basic definition of Fair Market Value and four extended versions. The Fair Market Value in Continued Use with Assumed Earnings and the Fair Market Value in Continued Use with an Earnings Analysis are not applicable, because the available data does not contain information about business earnings. This information is also not otherwise available. The remaining extended definitions (i.e. Fair Market Value – Installed and Fair Market Value – Removed) take into account the costs of installation and removal respectively. The dataset does not include these costs, so these definitions do not apply either. Therefore, the base definition of Fair Market Value is the most applicable definition.

2.2 VEHICLE VALUE DETERMINATION

With a clear definition of value, it is important to identify current valuation approaches used in the rail vehicle market and markets for other transport vehicles. First, insight is given in the methods used for the valuation of rail vehicles, followed by aircraft and ships.

2.2.1 RAIL VEHICLE VALUATION

Scientific theory currently lacks comprehensive research into the determinants of rail vehicle value, whilst there are ample examples of companies active in rail vehicle valuation. This means that in practice there is knowledge about the how and what of rolling stock appraisal, built on expertise and everyday business experience. European companies active in this market include, HEROS Helvetic Rolling Stock (2016), Rail-Assets (2016), RTS Infrastructure (2016), SCI Verkehr (2016a) and TÜV SÜD (2014).

HEROS Helvetic Rolling Stock's goal of rail vehicle valuation is to *"determine the technical value and time-related market value of a railway vehicle systematically and derive it depending on the individual general conditions"* (2016). As such, the company distinguishes both technical and market related determinants with the inclusion of age as a factor of influence. Furthermore, HEROS states that its knowledge of value determinants comes forward from its expertise and market knowledge, with the latter being the result of monitoring sales and purchases of rail vehicles. Although still an analogue approach, it supports the basic assumption that there is a relation between technical and market related factors on the one hand and value on the other hand.

HEROS differentiates between two forms of vehicle valuation with different purposes. The first form is to determine the book value of a vehicle to provide *"indications of the condition and residual value risk in the lifetime of the vehicle"* (HEROS Helvetic Rolling Stock GmbH, 2016). According to the company, this is mostly used in the evaluation of how certain life cycle strategies regarding use, maintenance and modernization influence residual value and the risks these strategies bring along. The second form of valuation is to determine the market value of rail vehicles in light of a possible remarketing process. Supporting this difference in valuation purposes, Rail-Assets (2016) states that the sales income is normally not similar to the residual book value: *"Hierbei ist zu beachten, dass die Verkaufserlöse in der Regel nicht den buchhalterischen Restwerten entsprechen"*. This is the case because the market value includes the additional effect of supply and demand coming together, whilst the book value forms the basis but is the result of a basic accounting formula (Equation 3). Thus, determining the fair market value of rail rolling stock requires a different approach than regular book value calculations. Especially since these calculations do not give insight into the determinants of rolling stock value and their relation with the value. Also, this way there is no factor included with respect to the condition of the vehicle.

$$\begin{aligned} Book\ value = {} & Purchase\ price\ (new) + Price\ additionally\ installed\ features \\ & - Accumulated\ depreciation - Impairment\ charges \end{aligned}$$

EQUATION 3: BOOK VALUE CALCULATION

In many of its appraisal projects, SCI Verkehr (2016a) has used a valuation method to determine the value stability of rolling stock that not only include a technical valuation, but also an outlook into the achievable future earnings under certain market developments. In some cases, SCI Verkehr also includes the influences of different maintenance programmes on value. Based on the different definitions of value as set out in Section 2.1, SCI Verkehr uses the *Fair Market Value in Continued Use with an Earnings Analysis* as a definition for value. However, such a method is only suitable if detailed information is available about operational costs and projected revenues. Often, this information is considered to be commercially sensitive and not made public.

2.2.2 AIRCRAFT VALUATION

In their paper *Aircraft Valuation in Dynamic Air Transport Industry* (2010), Gorjidooz and Vasigh state that *"Factors determining an aircraft's value not only include the physical characteristics of the aircraft, such as size, age, seat capacity, fuel efficiency and physical condition, but also include maintenance status and maintenance documentation; operating expenses and revenue; demand and its elasticity; inflation rates and interest rates; fuel cost; safety issues and regulation; and finally, environmental regulations"*. Identifying both market related and technical factors, Gorjidooz and Vasigh acknowledge the existence of factors relating to age, capacity, earnings and features. Additionally, they identify the condition of the aircraft with respect to maintenance, but lay emphasis on the technical characteristics or features in combination with age: *"…technological progress that reduces the operating costs of new aircraft , or environmental regulations that restrict older aircraft, or higher fuel prices, would have dampening effects on value of old wide-body aircraft*". Furthermore, it is stated that the value of an aircraft is directly related to operating costs and that air vehicles are retired as soon as the required load factor to break-even exceeds the capacity, with the operating costs being determined by both technical and market related factors such as: "*fuel efficiency, range, seat capacity, maintenance expenditures, and airport fees*". In general, Gorjidooz and Vasigh state that the higher the operating costs, the lower the value of an aircraft becomes.

Earlier, Vasigh and Erfani (2004) distinguished internal and external factors for a Net Present Value accounting technique. Internal factors include aircraft specifications (i.e. features), age, size (i.e.

capacity) and maintenance conditions. Next to internal factors, external factors are identified, such as market mechanisms with respect to supply and demand (e.g. even older aircraft may become wanted again in case of a shortage of newer aircraft or when fuel prices are sufficiently low). Futhermore, Vasigh and Erfani mention the importance of technological progress and environmental regulations: "*Technological progress reducing operating costs of new aircraft and environmental regulations, in combination with high fuel prices, would have dampening effects on the values of old equipment*". One could say that the older the asset, the higher operating costs are. Additionally, the more stringent the legislation concerning its use become, the higher the costs will be to operate the asset. The more expensive the asset gets to operate, the lower its value becomes. The reason for distinguishing internal and external factors is that they both have a different influence on the value of an aircraft according to Vasigh and Erfani. External (market) factors may influence the valuation of all commercial aircraft, regardless of internal factors such as age or manufacturer.

Gibson and Morell (2005) followed a cash-based approach in their paper *Theory and Practice in Aircraft Financial Evaluation* (2004). In this paper, they explore different methods for the financial evaluation of aircraft, distinguishing a basic approach based on Direct Operating Cost (DOC) comparison and more advanced approaches using Net Present Value (NPV) as a starting point. They mention that both DOC and NPV approaches have disadvantages. Where DOC does not take non-cash forms of costs into account, nor the time value of money, NPV does not include the economic uncertainties that an open market creates. The latter is the result of taking a general discount rate applicable for the whole industry. Furthermore, they state that NPV does not incorporate an estimation of the cost of capital, nor does it value "*the flexibility offered by manufacturer options and operating leasing*". DOC is a financial evaluation method and determines value by means of an earnings analysis, taking into account profits, losses and deprecation. Even though age is included through depreciation, it focuses on operational characteristics and non-cash attributions of technical features cannot be included. Moreover, the value of a vehicle determined through a financial approach may not reflect its fair market value. Regarding the NPV, the biggest danger is the discount rate. Gibson and Morell state: "*When using cash-based investment appraisal tools such as NPV, there is strong temptation to compensate for the volatility of the industry by artificially increasing the discount rate used in the analysis, thus making the project more difficult to justify*". Gibson and Morell acknowledge the lack of market factors by suggesting their inclusion.

In practice, ASCEND Flightglobal Consultancy (2014) defines the *Fair Market Value* as *"the value an aircraft can best achieve under today's open market conditions"* or more specifically *"The Market Value reflects what might be expected from the result of a single transaction conducted in an orderly manner, within a reasonable period of up to 12 months, between a willing buyer and willing seller, with the aircraft free of any lease or charge".* In their valuation methods, ASCEND *"takes into account age and specification of the asset in order to determine the Current Market and Base Values"*. This indicates that in aircraft valuation, factors related to age and technical features are of influence. ASCEND also acknowledges that there are differences between various aircraft related to combination of the role the aircraft have and their specifications. On a very basic level, the company distinguishes fixed-wing aircraft and helicopters, but also within these groups differences are distinguished. ASCEND illustrates this with helicopters used for VIP purposes and those used for oil and gas support functions, as both operate in different markets with different economic principles. Besides age and specifications, this indicates the existence of sectors in aircraft valuation. According to the company, maintenance condition and physical condition are also of influence. However, where the maintenance condition can be included on a desktop basis, the physical condition of an aircraft can only be included after an on-site inspection of the aircraft.

For commercial aircraft, International Bureau of Aviation (IBA) uses a similar principle predicting the aircraft value using age and market data. Subsequently, it corrects this for specific technical features so that it *"not just reflects a 'text book' example"* (IBA Group, 2016). IBA describes these specifications as *"Measurable Effects"* and gives examples such as engine model/thrust, winglets and cargo loading systems (IBA Group, 2014). More detailed examples of aircraft parameters used by IBA, include age related factors, such as build and delivery dates, and capacity related factors, such as the number of seats and belly volume (IBA Group, 2010). There is no mentioning by IBA of distinguishing groupings of aircraft with similar economics. The existence of such groupings exist is shown by Janssens (2016) for the business aircraft segment, in which five groups are distinguished: jet aircraft, turboprop aircraft, single-engine piston aircraft, multi-engine piston aircraft and helicopters. On a higher level, The Aircraft Value Analysis Company (2016) distinguishes the following categories: commercial jets, turboprops, business aircraft and helicopters.

2.2.3 SHIP VALUATION

For ships, Koehn shows in his Ph.D. Thesis *Generalized Additive Models in the Context of Shipping Economics* (2008) that technical characteristics of chemical tanker vessels are of influence on the second-hand prices of those vessels. Also, he identifies the importance of age, capacity and market conditions (i.e. ship earnings). Indirectly, sectors are distinguished by Koehn, who limits himself to chemical tankers, as their technical features are more heterogeneous and specialised than regular tankers and dry bulk carriers. This indicates that there are different subgroups of ships with similar economics that can be modelled together. Having established five broad factors (i.e. sectors, age, capacity, earnings and features) that are of influence but that are also common for other kinds of ships, Koehn adds the importance of other, sector-specific, factors.

In his Ph.D. Thesis, Koehn builds on previous work by Stopford (1997), who distinguishes four different determinants of value: freights rates, age, inflation and expectations. Freight rates are linked to vessel value through a system of supply and demand where the market for ships and shipping meet. Age is of influence through deprecation of the asset over time. This is often considered linear over a period of 20 to 25 years in practice according to Stopford. Although considered important, these four broad factors are not fully considered by Stopford, who adds to the relevance of technical characteristics specific to vessels.

Compared to Koehn, previous work by Adland and Koekebakker (2007) includes only the size and age of the ship, as well as *"the state of the relevant freight market"*. They show that both technical and market factors are of influence and base their findings on the use of cross-sectional transaction data, rather than the time-series models used until then. Additionally, they find non-linear relationships between value determinants and value. Pruyn (2011) mentions two benefits of Koehn's method compared to the parametric approach used by Adland and Koekebakker:

- the possibility to incorporate non-parametric components and thus more dimensions
- *"reliable results are provided using moderately sized samples"*

A Harvard Business School case by Esty and Sheen (2010) not only takes the findings of Adland & Koekebakker (2007) into account. It also shows that value estimation can be done by comparing the value of ships with similar technical features to the vessel of interest, adding to the importance of technical features. Researchers illustrating the influence of the state of the shipping market on the value of vessels include Beenstock (1985), Haralambides et al. (2005) and Pruyn et al. (2011). Beenstock (1985) links the freight market to the market for second-hand ships with a theoretical model to capture market influences on second-hand values.

VesselsValue (VV) has practical experience with the valuation of cargo vessels. VV uses market data and ship-specific technical features to estimate the fair market value with a semi-parametric model. Five broad explanatory factors of value – of both technical and financial nature – are identified, namely: *Sectors*, *Age*, *Size*, *Earnings,* and *Features* (Adamou, 2011). Maritime Strategies International (Bartlett, 2012) acknowledges the existence of ship sectors and the influence of age, size, earnings and technical factors. Factors included as indicators of the state of the market include the development of newbuilding and scrapping prices. This corresponds with findings of Pruyn et al. (2011), who conclude that ship valuation models should include the following variables: newbuilding price level, order book size, earnings and fuel consumption costs, age and deadweight tonnes.

2.3 SECTORS IN RAIL ROLLING STOCK

The aircraft industry and shipping industry both distinguish groupings of vehicles with similar economics. In Section 2.2, some examples have been mentioned, illustrating this differentiation in valuation. For ships, a first differentiation in river vessels and sea-/ocean-going vessels can be made and subsequently in cargo and passenger carrying vessels. For example, for ocean-going cargo vessels further categorisation based on cargo and size is possible into Aframax, Capesize, Chinamax, Handymax/Supramax, Handysize, Malaccamax, Panamax/New Panamax, Q-Max, Seawaymax, Suezmax, VLCC and ULCC (Maritime Connector, 2016). This structure is illustrated in Figure 4.

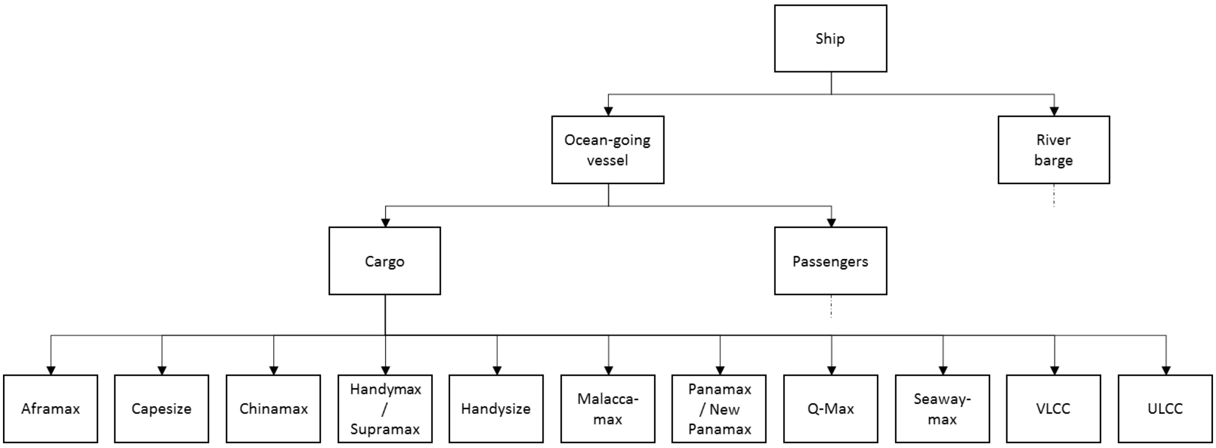

FIGURE 4: ILLUSTRATION OF SECTORS - SHIPS

Within the aircraft industry, a breakdown in sectors on multiple levels can be found in Figure 5, starting with an initial classification into categories (e.g. fixed-wing aircraft, helicopters, gliders). Taking fixed-wing aircraft as an example, these aircraft categories exist of classes such as single-engine (land), single-engine (sea), multi-engine (land) and multi-engine (sea). Subsequently, there are segments of aircraft, such as jet, turboprop and piston aircraft. Ultimately, there is the type of aircraft involved, which can be an A380-800, an ATR72-600, a B737-800 or any other aircraft type.

In some cases, a differentiation is made between narrow- and wide-body aircraft, which is then positioned between segments and types. Also, some consider the distinction between land and sea aircraft not to be positioned within classes but between categories and classes. As there is some debate about the position of the distinction between land and sea aircraft, Figure 5 illustrates the breakdown in sectors solely for land aircraft. Furthermore, in contrast to ships, a distinction between passenger and cargo aircraft is often not made for the reason that aircraft are often able to carry a combination of passengers and cargo simultaneously.

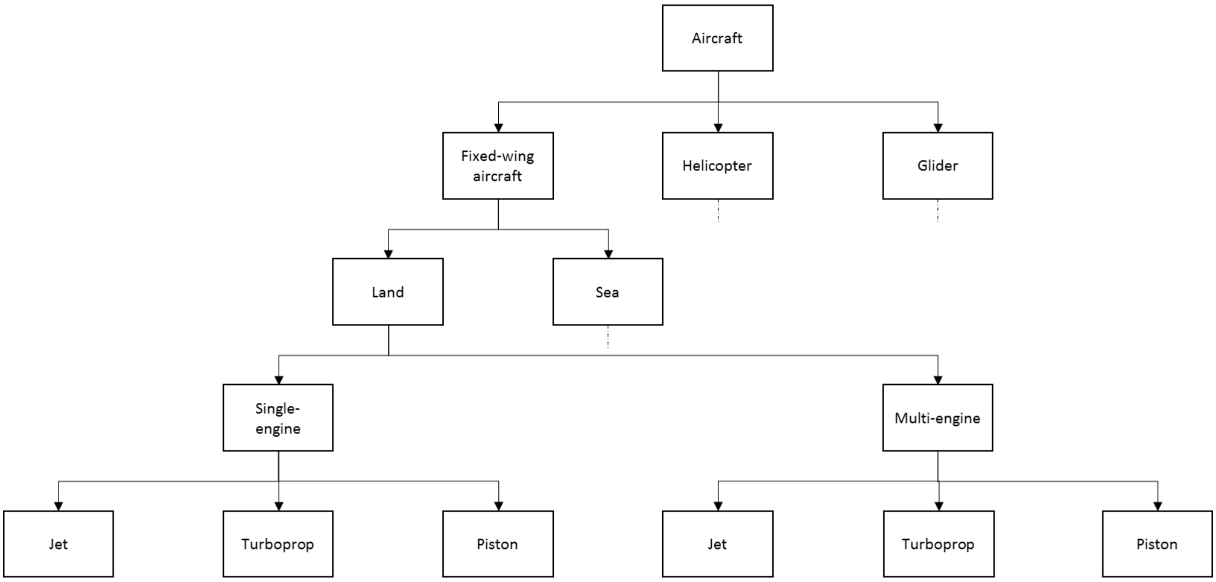

FIGURE 5: ILLUSTRATION OF SECTORS - AIRCRAFT

Within the rail rolling stock industry, groupings of rail vehicles with similar operational characteristics exist too. This is visualized in a basic way in Figure 6. The essence is an unspecified rail vehicle, which can either provide traction itself or which is powered by a different rail vehicle. Powered vehicles include locomotives, multiple units and railcars, trams/light rail vehicles and metros. Unpowered vehicles include freight and passenger wagons. Specialized vehicles such as engineering vehicles are excluded as they are mostly marketed differently due to their purpose-built and special nature.

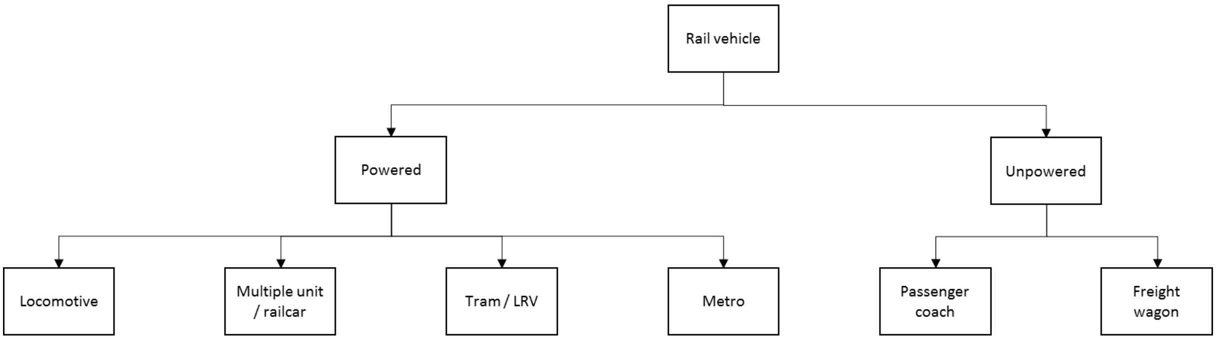

FIGURE 6: GENERAL SECTORS - RAIL VEHICLES

Further differentiation into subsectors is possible for most general sectors distinguished in Figure 6. Of the powered rail vehicles, metros can be subdivided into metro vehicles using regular tracks or rubber-tired metros. Of the unpowered vehicles, passenger coaches can be subdivided into regular passenger coaches, restaurant coaches, sleeping coaches, etc. In Chapter 3, data collection and availability are further explained, resulting in a focus on locomotives and freight wagons. Further subdivisions of sectors are limited to locomotives and freight wagons in the following subsections.

2.3.1 LOCOMOTIVES

Two main types of locomotives exist: mainline locomotives and shunting locomotives (Figure 7). The former are used for line-haul operations, the latter are used for servicing sidings, terminals and shunting yards (Nieuwenhuis, 2012). One could argue that a subdivision according to propulsion system could be applicable in a similar fashion to aircraft: a differentiation into electric and diesel locomotives. This distinction is used by SCI Verkehr when performing market studies covering the worldwide market for electric (SCI Verkehr, 2016b) and diesel locomotives (SCI Verkehr, 2015).

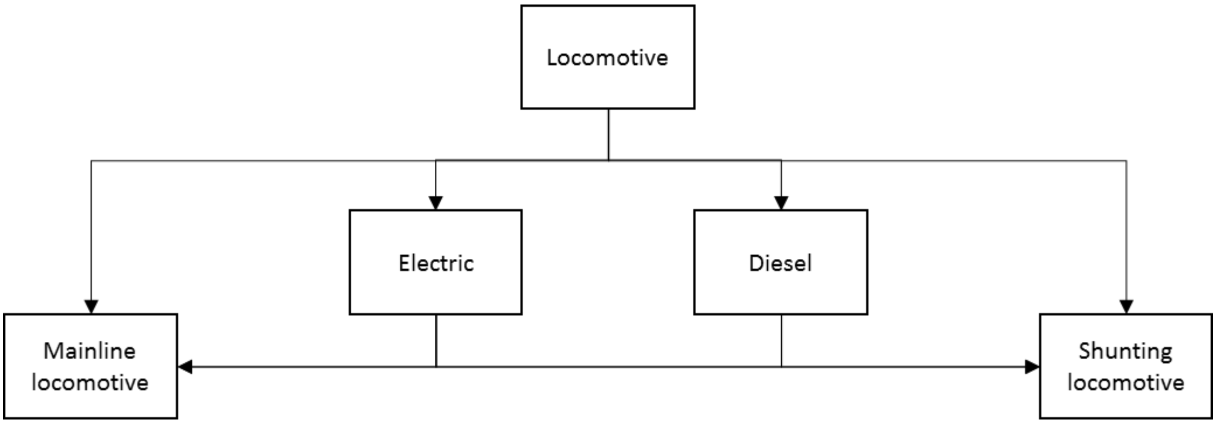

FIGURE 7: SUBDIVISION LOCOMOTIVE TYPES

Today's railway industry continues to innovate, introducing powered rail vehicles to the market with various drivetrains. Market-ready drivetrain variants include:

- hybrid diesel-battery
- full battery-powered
- single-engine diesel-powered
- twin-engine diesel-powered
- bi-mode (overhead power and/or diesel power and/or batteries)

Manufacturers offering new drivetrain variants include Alstom (2016), Stadler Rail (2016a; 2016b) and Vossloh Locomotives (International Railway Journal, 2012). Other developments include the hydrogen fuel-cell multiple unit by Alstom introduced in 2016 (Railway Gazette International, 2016), and a CNG-powered locomotive introduced in trial service in the Czech Republic by CZ LOKO in cooperation with national operator České dráhy (Railway Gazette International, 2015). Despite the variety of drivetrains, this thesis limits itself to the most widely accepted variants: electric, diesel and hybrid electro-diesel.

Another possible differentiation, predominantly for mainline locomotives, relates to the purpose of the vehicle and is mostly made by rolling stock manufacturers in the designation of the different locomotives in the companies' product portfolio. For its TRAXX locomotive family, Bombardier Transportation (2016a) uses the letter P for locomotives configured for passenger services (e.g. TRAXX P160 AC2) and the letter F for freight versions (e.g. TRAXX F140 AC2). For its EuroSprinter locomotive family, Siemens designated the various models in a similar way by using the letter F for freight versions and the letter U for universal locomotives intended for both passenger and freight operations. Even though such indications hint at differences between passenger, freight and universal locomotives, in practice many freight locomotives are also suited and/or equipped for use as passenger locomotives and vice versa. Therefore, the distinction between these freight, passenger and universal locomotives is more of a theoretical nature. Furthermore, especially for new, highly standardized and modular products, freight versions can be changed easily into passenger versions and vice versa. In some cases this transformation is merely software-related. As the economics of these vehicles do not differ substantially, the groups *passenger*, *freight* and *universal* are not considered sectors.

2.3.2 FREIGHT WAGONS

The broad variety of uses enables a more detailed categorisation into subsectors. Nieuwenhuis (2012) illustrates the versatility of freight wagons with the former motto of Dutch national rail operator NS *'Voor elk vervoer een wagen'*, which loosely translates to *'a freight wagon for every type* *of cargo'*. The broad range of wagons available becomes clear from the official classification of freight wagons issued by UIC in leaflet 438-2 (UIC, 2004b). This classification uses a system of letters that refer to the most important technical characteristics. It consists of an upper-case letter and a varying number of lower-case letters. The upper-case letter indicates the class of wagon (e.g. open, covered, tank) and the wagon construction type (regular or special). The meaning of the upper-case letters is explained in Table 6. The lower-case index letters refer to the main technical features of the wagon. Wagon class U is a special category and includes both wagons for exceptionally heavy or out-of-size loads and silo wagons for powders or semi-solid slurries. In this research, the latter are included, as special and purpose-built vehicles are excluded.

TABLE 6: FREIGHT WAGON CLASSES

WAGON CLASS	**WAGON TYPE**
E	Regular open wagon with high sides
F	Special open wagon with high sides
G	Ordinary covered wagon
H	Special covered wagon
I	Temperature-controlled wagon
K	Ordinary two-axle flat wagon
L	Special flat wagon with separate axles
O	Composite open wagon
R	Ordinary bogie flat wagon
S	Special bogie flat wagon
T	Wagon with opening roof
U	Special wagon
Z	Tank wagon
Source: UIC (2004b)	

This UIC classification can be used to create subsectors for freight wagons. In a similar fashion as the naming conventions for cargo vessels, the classification is based on technical characteristics of wagons, size and in some cases their purpose or intended use. Figure 8 shows the further specification of subsectors for this group of rail vehicles.

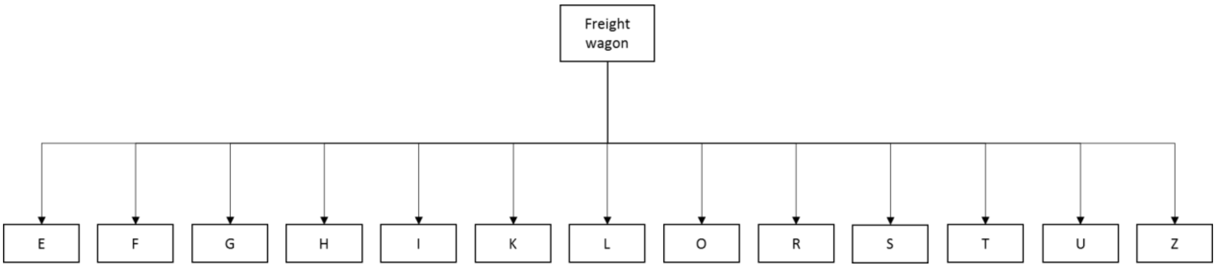

FIGURE 8: SECTORS FOR FREIGHT WAGONS ACCORDING TO UIC CLASSIFICATION

Such a comprehensive classification may give the impression that every single class contains only one type of freight wagon, but some classes host multiple types of wagons. Table 6 contains a number of examples of this. Freight wagon class L hosts both container wagons and car transporters, and wagon class S contains both intermodal wagons of different kinds but also metal coil/plate transporters. According to Nieuwenhuis (2012) intermodal wagons can be divided into four groups:

- wagons suitable for containers and swap bodies
- wagons additionally suitable for complete trailers
- wagons suitable for rolling highway services (German: 'Rollende Landstrasse') able to transport complete truck and trailer combinations
- wagons for specialized containers, such as ACTS intermodal roller containers

The inclusion of multiple vehicle types in a single class is problematic when directly translating them into sectors. For example, when demand for steel and thus for steel transport is weak, this negatively influences the selling prices of metal coil/plate carriers. When the market for intermodal transport is strong, this results in two different market dynamics within one sector (i.e. class S). From a technical perspective, intermodal and metal carrying wagons differ too. Intermodal wagons are relatively light-duty vehicles, whilst their metal carrying counterparts are often heavy-duty vehicles and may feature more than two axles per bogie to accommodate heavy loads, which is rare for container wagons.

Therefore, wagon classes are grouped by cargo category, using definitions used in shipping. Ligterink and Velsink (2012) mention a division in dry bulk, liquid bulk, containers, roll-on/roll-off and other goods. Table 7 lists the new cargo categories distinguished for freight wagons, taking cargo classification categories from shipping into account. The categories *Dry bulk* and *Liquid bulk* are re-used, but the category containers is now the category *Intermodal* to also include swap bodies and trailers for example. Other goods, in shipping better known as general cargo, include several forms of break-bulk cargo. Here, *Break-bulk* is considered as a single category, comprising regular piece goods, unit load devices, refrigerated pieces of cargo, etc. Because of the unique nature of the freight wagons, two types of cargo are included separately for rail vehicles, namely *Cars* and *Coils/Plates*.

Table 7 reveals that some wagon classes are linked to multiple cargo categories. The class-related index letters determine which cargo category applies. For example, a type Shimmns coil carrier belongs to the cargo category *Coils/Plates*, being a special bogie flat wagon (S), for sheet metal coils loaded eye-to-side (h), with movable top cover and fixed-end walls (i), with four axles and a useful length less than 15m or with six or more axles and a useful length less than 18m (mm), with four axles and a maximum permissible load of more than 60 tonnes, operating under speed regime s. Similarly, a type Sgjs container wagon belongs to the cargo category *Intermodal*, being a special bogie flat wagon (S), for transporting large containers up to 60 feet in length with the exception of medium-sized pa-containers (g), with shock-absorbing device (j), operating under speed regime s (s).

TABLE 7: FREIGHT WAGON SECTORS BASED ON CARGO CATEGORIES

CARGO CATEGORY	REMARKS	UIC WAGON CLASSES
Dry bulk	Ores, grains, fertilizers, etc.	E, F, T
Liquid bulk	Liquids, gases, slurries, powders, etc.	U, Z
Intermodal	Containers, swap bodies, trailers, etc.	K, L, R, S
Break-bulk	Pallets, boxes, fresh food, timber, pipes, etc.	G, H, I, K, O, R
Cars	Cars, vans, etc.	H, L
Coils/Plates	Metal coils and plates of different sorts, such as steel, aluminium, etc.	S

The result is a categorisation as depicted in Figure 9. The wagon classes as differentiated in UIC leaflet 438-2 (with dashed lines) are now part of six broader sectors with their own characteristics. These characteristics do not only include the technical characteristics from a UIC class perspective, but also relate to the intended use of the wagon in relation to the cargo carried. Furthermore, by using cargo categories used in shipping as a basis, six different market segments become visible.

2.4 DEPRECIATION: THE INFLUENCE OF AGE ON VALUE

There are various ways to determine the influence of age on value. The most commonly used process is known as depreciation, which is the allocation of the costs of an asset over its estimated useful life, taking into account the cost of the asset at the moment of purchase and its residual value at the end of its useful life. Most depreciation methods are accounting techniques, which are based either on time or on use. In general, four techniques are most commonly used. Depreciation methods based on time include the Straight Line Method, the Declining Balance Method and the Sum of the Years' Digits method. A method based on use is the Units of Activity method. Each method has its own dynamics over the estimated depreciation period. As indicated by Weil et al. (2013), the variety of methods shows that there is considerable flexibility in the choice for an appropriate depreciation method. As a result, agreement does not always exist what methods are applicable and when.

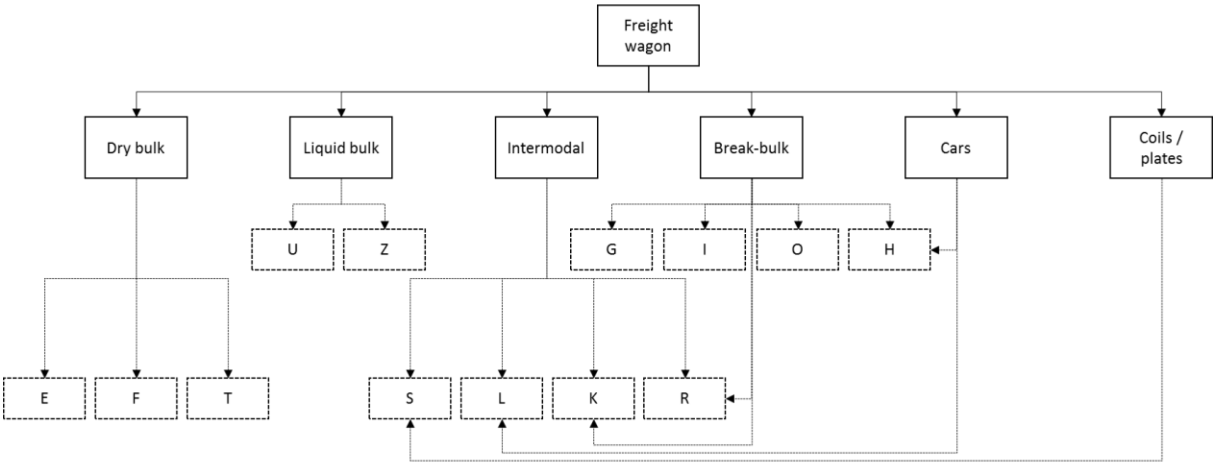

FIGURE 9: FREIGHT WAGON SECTORS BASED ON CARGO CATEGORIES

2.4.1 STRAIGHT LINE METHOD

The Straight Line Method is a linear depreciation technique using a fixed rate over the estimated useful life of the asset, often the technical life span of that asset (Equation 4). The Straight Line Method is useful in times of uncertainty, when it is hard to estimate the economic benefits of an asset throughout its useful life. When these benefits can be assumed to be spread equally over the asset’s useful life, this method is appropriate.

$$Yearly\ depreciation = \frac{Value\ (new) - Value\ (residual)}{Estimated\ useful\ life}$$

EQUATION 4: DEPRECIATION ACCORDING TO THE STRAIGHT LINE METHOD

Freight wagon lessors in the United States use this method to determine the residual values of wagons (American Railcar Industries Inc., et al., 2012). In Europe, locomotives and freight wagons tend to be depreciated this way (B. Wagner, personal communication, January 18, 2017). Depreciation guidelines of DB (2015), Eurostar (2013), ÖBB-Infrastruktur (2015), NS (2015), NMBS Groep (2011) and SNCF (2016) support the use of linear depreciation for rail vehicles.

Guidelines differ per country. A depreciation period of circa 30 years is common in The Netherlands and 25 years in Germany (B. Wagner, personal communication, January 18, 2017). Table 8 shows a selection of commonly used depreciation periods in Europe.

TABLE 8: OVERVIEW COMMON DEPRECIATION PERIODS

OWNER	COUNTRY	DEPRECIATION PERIOD
DB	Germany	10-30
Eurostar	United Kingdom	30
ÖBB-Infrastruktur	Austria	5-25
NS	Netherlands	20
SNCF	France	30

The used residual values also differ. Whilst a residual value of circa 10% of the new value is common in The Netherlands, NMBS Groep (2011) uses 0%. The resulting book value of a rail vehicle combined with a deviation factor for technical aspects and conditions results in the projected selling price. The final market value is the result of the interaction between supply and demand.

2.4.2 DECLINING BALANCE METHOD

Where the Straight Line Method assumes that the benefits of an asset are spread equally over the asset's useful life, the Declining Balance Method is based on the assumption that these benefits decline through an asset's useful life. Correspondingly, the amount of depreciation decreases over the years. This can be realistic for assets of which their usefulness is subject to technical progress, assuming newer, more advanced assets are more useful. The disadvantage of this method is that the net book value in the final year is never equal to the residual value determined beforehand. Therefore, the surplus in book value is charged in the final year to correct this. The Declining Balance Method follows the formula as presented in Equation 5.

$$Yearly\ depreciation = (Net\ book\ value - Value\ (residual)) \times\ Estimated\ depreciation\ rate$$

EQUATION 5: DEPRECIATION ACCORDING TO THE DECLINING BALANCE METHOD

2.4.3 SUM OF THE YEARS' DIGITS METHOD

The Sum of the Years' Digits Method uses an absolute amount with which the yearly depreciation of an asset decreases. It is realistic in calculating higher deprecation values per year early in an asset's useful life than in later years. Even though the calculations are slightly more extensive than the Declining Balance Method, it does not have to cope with surplus residual value that must be artificially depreciated in the last year. The Sum of the Years' Digits Method is a stepwise accelerated depreciation method following the formula as presented in Equation 6.

$$Yearly\ depreciation = \frac{Remaining\ useful\ life}{Sum\ of\ the\ year's\ digits} \times (Value\ (new) - Value\ (residual))$$

EQUATION 6: DEPRECIATION ACCORDING TO THE SUM OF THE YEARS' DIGITS METHOD

2.4.4 UNITS OF ACTIVITY METHOD

The principles behind the Units of Activity Method are slightly different from those behind the previous three depreciation techniques. The Units of Activity Method directly links the yearly depreciation to the extent in which the asset is used. Increased use results in higher depreciation charges, reduced use in lower charges. The formula used for this method is presented in Equation 7.

$$Yearly\ depreciation = \big(Value\ (new) - Value\ (residual)\big) \times \frac{Amount\ of\ activity\ completed}{Est.total\ activity\ of\ asset}$$

EQUATION 7: DEPRECIATION ACCORDING TO THE UNITS OF ACTIVITY METHOD

This method is useful for moving assets, such as rail vehicles, that are subject to wear during their useful life. There is a disadvantage and that is the assumption that assets do not depreciate when they are idle. However, in practice vehicles continue to depreciate, even when idle.

2.4.5 COMPARISON OF DEPRECATION TECHNIQUES

A fictive example is used to visualize the four deprecation methods. A locomotive with a value of €1,000,000 is the subject of the depreciation. After ten years, no residual value is left. For the Declining Balance Method a depreciation percentage of 40% is used. The Units of Activity Method uses a varying number of kilometres with an average of 250,000 kilometres per year.

Figure 10 shows the different deprecation profiles. Where the Units of Activity Method approaches the Straight Line Method in this case, the Declining Balance Method and Sum of the Years' Digits Method differ greatly. Where the other methods lack residual value at the end of the ten-year period, this is not the case for the Declining Balance Method. Initially, it results in higher yearly depreciation charges, but these charges decrease until year 9, after which the remaining residual value is charged in the final year. Appendix A1 contains the supporting calculations.

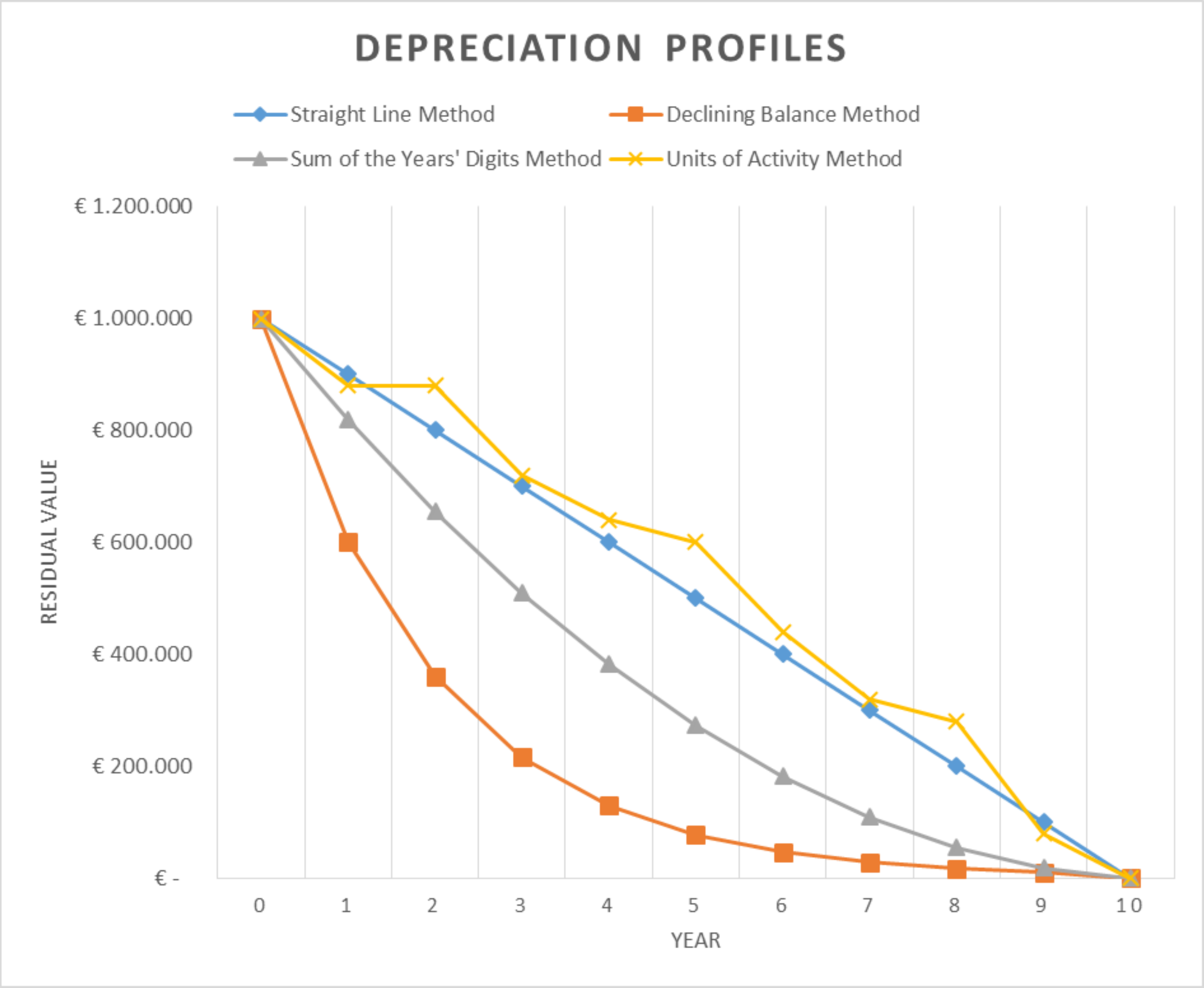

FIGURE 10: COMPARISON OF DEPRECATION PROFILES

2.4.6 REVIEW OF DEPRECIATION TECHNIQUES

All four techniques have benefits and disadvantages. Although the Straight Line Method is easy to apply and used in practice, it may underestimate the depreciation charge in early years. The Declining Balance Method overcomes this by assuming that the yearly depreciation charge decreases over time in line with decreasing usefulness of assets over the years. This makes it useful for assets that contain a high amount of technology, such as locomotives. The disadvantage is that it charges the surplus of residual value in the final year, so it can overestimate the true amount of depreciation charged in the last year. This is overcome by the Sum of the Years' Digits Method that does consider decreasing charges, but that does not need to charge remaining residual value in the final year. All time-based techniques fail to take other aspects than age into account. Although the Units of Activity Method may be considered useful for moving assets, it underestimates the effects of age when they are idle. Also, this method is not easily used in estimations of activity beforehand, but better post-hoc when the activity has been performed.

Note that the four considered methods are accounting techniques to estimate the book value and not the fair market value of assets (Jackson, Liu, & Cecchini, 2009). By judging the dynamics of their functions, the importance influence of age on vehicle value is shown, especially as the book value forms the basis for the market value in practice. Additionally, insight is given in the shape of the possible relation between age and value. Furthermore, it gives insight in the disadvantages of regular accounting techniques as they fail to include other aspects than age (time-based approaches) and utilization (activity-based approaches). This research is to give insight in the influence of age on the fair market value in conjunction with technological and market factors.

2.5 THE DEFINITION OF CAPACITY

In ship valuation, a positive relation between vessel value and the capacity of the vessel has been determined for bulk tankers by Alizadeh and Nomikos (2003) and for tankers by Syriopulos and Roumpis (2006). VesselsValue (Adamou, 2011) states that ship capacity is *"typically measured in deadweight tonnes (DWT) for tankers and bulk carriers, twenty-foot equivalent units (TEU) for containerships and cubic metres (CBM) for LPG and LNG ships"*, showing there is no sole indicator of capacity. Each individual sector can have its own version. For cargo and passenger ships, suitable indicators are easily identified. It gets complicated when a notion of capacity lacks, such as for tugs.

2.5.1 LOCOMOTIVES

Locomotives can have a double function, namely to haul freight or passenger trains. In contrast to multiple units and railcars, locomotives are powered vehicles that are unable to transport cargo or passengers. Therefore, no direct indicator of capacity can be assigned.

One can consider alternative indicators that indirectly measure the capacity of a vehicle, such as the starting tractive effort. Although a higher starting tractive effort enables heavier trains to be moved from standstill (Hansen & Pachl, 2014), it is problematic to use it as an alternative capacity indicator. The reason for this is that heavy trains may exist of empty wagons with a high tare weight and relatively low capacity. Finally, the capacity of a train is still determined by the wagons, so an indirect capacity indicator cannot be defined.

2.5.2 FREIGHT WAGONS

For freight wagons, it is possible to use the maximum load in tonnes as a capacity indicator. This is the most general approach and the advantage is that it can be applied to the six wagon sectors (i.e. dry bulk, liquid bulk, intermodal, break-bulk, cars and coils/plates). Two possibilities exist to include the maximum load as a capacity indicator, namely:

- the maximum load per axle load category
- the maximum load of the vehicle at the highest permissible load limit category

The load limits of freight wagons are listed per category of railway line. Each category (i.e. A, B, C, D, E, F and G) has a corresponding permissible axle load (Table 9). The higher the category assigned to a railway line is, the higher the weight of a train using that line may be. The maximum load per axle category is calculated according to Equation 8, in which '*x*' represents the line category.

Freight wagons always carry inscriptions with the maximum permissible axle load per category (UIC, 2004a). Not every wagon can be loaded up until the highest category due to tare weight or technical limitations. Additionally, there are subcategories (i.e. B1, B2, C2, C3, C4, D2, etc.) related to the maximum vehicle mass per unit length. In this research, only the main categories are considered.

$$Load\ limit\ x = (Max. permissible\ axle\ load\ x\ \times number\ of\ axles) - Tare\ weight$$

EQUATION 8: LOAD LIMIT

Even though the maximum permissible load forms a convenient capacity indicator, there is a second option. It is also possible to use indicators related to the cargo type carried. This approach is similar to the approach used by VesselsValue's (2011), which uses different indicators for different vessel types. Also in aircraft valuation multiple ways to measure capacity exist, differentiating between maximum payload and maximum belly volume (IBA Group, 2010; Ackert, 2011), as well as passenger capacity (Gibson & Morrell, 2004; Justin, Garcia, & Mavris, 2010).

TABLE 9: AXLE LOAD CATEGORIES AND PERMISSIBLE LOADS

AXLE LOAD CATEGORY	MAX. PERMISSIBLE AXLE LOAD (T)
A	16
B	18
C	20
D	22.5
E	25
F	27.5
G	30
Source: UIC (2004a)	

To determine sector-specific capacity indicators for freight wagons, the product portfolios of several freight wagon producers active in the European market have been compared. This includes Ateliers d'Orval (2016), Astra Rail (Astra Rail, 2016), Duro Dakovic (2016), EKK Wagon (2016), Greenbrier (2016), Kockums Industrier (2016), Kolowag (2016), Legios (2016), Tatravagonka (2016b), Waggonbau Graaff (2016) and Waggonbau Niesky (2016).

DRY BULK

In shipping, the capacity of dry bulk carriers is referred to in deadweight tonnes (DWT), rather than cubic metres (Adamou, 2011; Ligteringen & Velsink, 2012). In contrast, freight wagons for dry bulk cargo are mainly marketed according to their maximum volume. For ore wagons, the maximum tonnage is equally important.The importance of volume as capacity indicator was witnessed at the InnoTrans 2016 trade fair in Berlin, where high-capacity bulk wagons were presented. Examples are a 102m^3 Tagnpps grain hopper by Astra Rail, a 60m^3 open box wagon for the UK by Astra Rail, a 101m^3 Tagnpps by Legios and a 95m^3 Tagnpps by Titagarh Wagons. The continuous development of wagons with increased cargo capacity supports the goal to make rail freight more cost-efficient.

LIQUID BULK

Freight wagons for liquid bulk, gases, powders and slurries are similarly marketed with a focus on the total volume of the tanks. This is analogue to LNG and LPG vessels in shipping, but contrasts the way capacity is measured for other tank vessels. The importance of volume could be witnessed at InnoTrans 2016 too. High-capacity wagons on display included a 73m^3 Zacens by Astra Rail, a 98m^3 Zacns by Legios, a 98m^3 'Jumbo Plus' Za(c)ns by Tatravagonka and a 113m^3 Zags by Greenbrier.

INTERMODAL

In shipping, the capacity of container ships is measured in twenty-foot equivalent units (20'), better known as TEU (Ligteringen & Velsink, 2012). In rail, intermodal wagon capacity is mostly measured in feet due to the larger variety of container sizes used in land transport. For example: 30' and 45' containers, swap bodies and (semi-)trailers. The requirements for these and other vertically (un)loaded load devices are stipulated in UIC leaflets 592 (2013) and 592-3 (1998).

BREAK-BULK

The capacity of wagons used to transport break-bulk or general cargo differs between wagon types due to the large variety in technical designs. This is caused by the nature of the cargo, which comes in many different forms and appearances. Where wood and pipes generally require long open wagons, palletized cargo requires covered high-volume wagons. As a result, the capacity indicators differ for various wagon types. For open wagons, the usable loading area is generally most important, whilst for covered wagons and wood carriers the loadable volume is of equal importance.

Cars

The maximum load capacity of car transporters is traditionally measured in tonnes and translates to a maximum axle load per loaded car. A secondary indicator is the number of cars that can be loaded, which is restricted by the number and type of wheel chocks available to secure the load. Using the number of wheel chocks as a capacity indicator, is thus problematic as more chocks do not automatically result in a higher capacity.

Coils/plates

In general, wagons used to transport metal coils, plates or ingots are heavy-duty vehicles able to cope with heavy loads. Their capacity is measured in tonnes.

2.5.3 Overview of rail vehicle capacity indicators

In the preceding subsections, possible notions of capacity for locomotives and freight wagons are listed. Table 10 gives a brief overview of the findings.

Table 10: Overview of capacity indicators per sector

Vehicle sector	**General capacity indicator**	**Class-specific capacity indicator**
Locomotive	n/a	n/a
Freight wagon		
- Dry Bulk	Tonnes	Cubic metres
- Liquid Bulk		
- Intermodal		Feet
- Break-bulk		Usable loading area
- Cars		Tonnes
- Coils/plates		Tonnes

2.6 The concept of earnings

In shipping, a correlation exists between the values of cargo ships and the (outlook for) freight earnings, and differences exist per sector (Adamou, 2011). Adamou mentions the use of spot rates, which result from the interaction between the supply of and demand for (charter) shipping services. Spot rates are linked to *"exception freight that is not covered by a contract"* (TransCore Freight Solutions, 2011). The principle behind this is that the interaction between the supply of and the demand for shipping services is of influence on the demand for ships.

In aircraft valuation, earnings influence value too. Justin et al. (2010) use the total airplane-related operating revenues, which reflect *"the ability of an aircraft to generate revenues and consists of the revenues generated by the cabin, the cargo-holds as well as the revenues generated by ancillary fees (baggage fees, carry-on fees) that airlines are now using"*. Similarly, Vasigh et al. (2010) differentiate between total passenger and cargo income. Both consider earnings to be only one element of influence on aircraft value and the importance of costs is emphasized. Vasigh et al. (2010) illustrates: *"We know that an airline executive would never purchase an aircraft that is calculated to return only $10 million over its useful life if the purchase price is more than $10 million"*.

The concept of earnings is used differently in the ship and aircraft valuation examples. Considering an application in rail vehicle valuation, both methods have benefits and disadvantages. Using transport rates is difficult because of the nature of the rail freight and passenger rail markets. Cargo flows by rail are mostly contracted en bloc on a long-term and scheduled basis (e.g. full trainload services and intermodal shuttles). The value of these contracts covers more than the transport service, so it is impossible to deduce the freight rates per unit of cargo or wagon. An exception is wagonload transport, in which transport of individual wagons is charged against specific rates.

In passenger rail, specific rates per passenger per fare zone are used. These are often clouded due to tariff differentiation (e.g. regional vs. high-speed trains, children or frequent travellers). Also, tariffs may be subsidized and the train operating contract as a whole may be subsidized as part of an operating franchise on behalf of (local) governments (Provincie Fryslân, 2004; Office of Rail and Road, 2015). Additionally, tariff structures differ between countries, making it difficult to use it as an indicator of earnings.

A possible alternative would be to use operating lease rates as an indication of the state of the market, based on the interaction of supply and demand. This requires lease rates to fluctuate over time, linked to differences in demand. However, using lease rates may be problematic. Firstly, operating lease rates are often not made public as they are considered to be sensitive information. Secondly, according to B. Wagner from Beacon Rail Leasing (personal communication, July 19, 2016), operating lease rates are held static, as they are linked to the purchase price. Fluctuating lease prices endanger the return on investment for the lessor.

Another option is using the order book size for new vehicles and/or the number of scrapped vehicles, as done by Beenstock and Vergottis (1989), Tsolakis (2005) and Bartlett (2012) in ship valuation. In a review of ship value estimation methods, Pruyn et al. emphasize the importance of these variables in addition to new building price levels and the result of operating revenues and costs.However, including revenues proves to be problematic for some rail vehicle types. Furthermore, it is not as common for rail vehicle producers as for aircraft producers to provide insight in order books. Traditionally, the performance of the rail transport market is measured separately for rail freight and passenger rail. For rail freight, the main indicator is the yearly number of tonne-kilometres, for passenger transport it is the yearly number of passenger-kilometres.

2.7 THE INFLUENCE OF TECHNICAL FEATURES ON VALUE

According to the theory of asset specificity, assets built for specific functions are limited with respect to redeployment into other functions due to their characteristics, which negatively influences market value (Church & Ware, 2000). Church & Ware identify four forms:

- physical-asset specificity
- site specificity
- human-asset specificity
- dedicated assets

Physical-asset specificity applies to rail vehicles and it implies that the more standardized vehicles are, the higher their resale potential is and the higher their market value. For example, electric rail vehicles built for use under multiple overhead power systems, for widely used track gauges or equipped with multiple train protection systems have a higher resale potential.

Chiesa et al. (2007) show that there are three main types of factors of influence on value:

- technical factors
- firm related factors
- transaction related factors.

Many technical features may be of influence on vehicle value, such as train protection systems. Price indications for retrofitting locomotives – of a type already approved for a country – show the important influence on value (W. Radstake, personal communication, February 25, 2016):

- PZB90 and/or LZB for Germany, ca. €60,000
- ATB EG or NG for The Netherlands, ca. €180,000
- ETCS, on average €350,000
- SCMT for Italy, ca. €500.000

SCI Verkehr (2016b) distinguishes technical factors as power rating and propulsion system (e.g. diesel, electric or hybrid). Investment firm Steiner + Company (2011) emphasizes the important effect of technical features as follows: *“Ein Mieter kann also mit einer im Jahr 2000 gebauten Lok bzw. Waggon die gleiche Leistung erbringen. Dadurch bleiben Gebrauchtloks und -waggons extrem preisstabil”*. The company goes into more detail by differentiating between diesel-electric, diesel-hydraulic, etc. Furthermore, Steiner + Company differentiates between shunting and mainline locomotives, indicating that the maximum speed is of importance too. Additionally, it mentions the effect of compliance with noise and exhaust emissions legislation. Amongst other factors that boost second-hand values, Metz & Radstake (2013) name a high number of country approvals and how modern a vehicle is relative to standards and regulations for new vehicles.

In other fields the influence of technical features on (moving) asset value is established too. In ship valuation, Koehn (2008) shows the relation between the technical features of chemical tankers and value. Furthermore, Koehn mentions the importance of other ship-specific factors, including the yard and country of build. Previous work by Adland & Koekebakker (2007) merely includes ship size, age and *“the state of the relevant freight market”*, but they acknowledge the importance of technical factors. A Harvard Business School case by Esty and Sheen (2010) not only takes the findings of Adland & Koekebakker into account, but also shows that value estimation is possible by comparing the values of technically similar ships.

For aircraft, Gorjidooz and Vasigh (2010) acknowledge the dependence of value on physical characteristics. They identify the following factors to be of influence: fuel efficiency, safety and environmental regulation compliance, maintenance status and documentation. They build on Vasigh and Erfani (2004) who distinguish internal and external factors, including technical features. Although many valuation models assume a normal state with respect to maintenance and condition, maintenance state is of influence on aircraft value (Gorjidooz & Vasigh, 2010; Ackert, 2011). In practice, ASCEND Flightglobal Consultancy (2014) considers *“the value an aircraft can best achieve under today’s open market conditions”* and *“takes into account age and specification of the asset in order to determine the Current Market and Base Values”*. International Bureau of Aviation (IBA) uses a similar principle predicting value with market data and correcting this for technical features so that it *“not just reflects a ‘text book’ example”* (IBA Group, 2016). IBA describes these as *“Measurable Effects”*, which include winglets and cargo loading systems for example (IBA Group, 2014).

2.8 CONCLUSIONS

2.8.1 VALUE DEFINITION OF CHOICE

Different definitions of value exist, from perceived value to a multitude of definitions used in asset appraisal. The definition of fair market value (“*An opinion expressed in terms of money, at which the property would change hands between a willing buyer and a willing seller, neither being under any compulsion to buy or to sell and both having reasonable knowledge of relevant facts, as of a specific date.*”) best suits the concept of value in this thesis.

2.8.2 KEY FACTORS (RAIL) VEHICLE VALUATION

Rail vehicle valuation is mostly based on practice. The influence of age, technical and market related factors on value is recognized, analogue to aircraft and ship valuation theory and practice. Despite the variety of methods, there is agreement about five key factors in vehicle valuation: *Sectors, Age*, *Capacity*, *Earnings* and *Technical features*. This thesis adopts them to research their influence in rail.

2.8.3 SECTORS IN RAIL ROLLING STOCK

In theory, sectors – groups of vehicles with sufficiently similar economics that allow them to be modelled together – exist for rail vehicles. Locomotives are best grouped by function (i.e. mainline vs. shunting operations) and the way they are powered (i.e. electric, diesel or a combination). Freight wagons are best grouped by cargo category, defined analogue to shipping: dry bulk, liquid bulk, intermodal, break-bulk, cars and coils/plates. Straightforward application of UIC freight wagon codes to define sectors is impossible, as multiple wagon types use the same coding letters.

2.8.4 THE INFLUENCE OF AGE ON VALUE

For tax reasons, the book value of locomotives and freight wagons is generally estimated using straight-line depreciation within the European rail industry. When corrected for technical features and state, the intended selling price is established. The final fair market value is the result of the influence of supply and demand on this selling price. Although the effect of age on value is considered linear, general asset valuation theory also proposes non-linear relationships.

2.8.5 CAPACITY INDICATORS FOR RAIL VEHICLES

A suitable notion of capacity for locomotives does not exist. Freight wagons have multiple ways to indicate capacity: through their maximum general capacity in tonnes or using sector-specific notions such as tonnes for car transporters and metal coil/plate carriers, cubic metres for dry and liquid bulk wagons, usable loading area for break-bulk wagons and the number of feet for intermodal wagons.

2.8.6 A CONCEPT OF EARNINGS FOR RAIL VEHICLES

Theory about ship and aircraft valuation marks the important influence of earnings on value, as an indication of the state of the transport market and indirectly of the state of the market for means of transport. Where ship valuation opts for spot freight rates and aircraft valuation for passenger and cargo revenues, the nature of the rail market does not allow the use of similar concepts. Using lease rates is problematic due to their static nature over time; using order book size is difficult as the rail industry is less transparent than the ship and aircraft industry. The state of the rail freight (in tonne-kilometres) and passenger rail transport markets (in passenger-kilometres) are considered the most suitable alternatives to include the effects of demand for rail transportation and thus for rail vehicles.

2.8.7 THE INFLUENCE OF TECHNICAL FEATURES ON VALUE

Basic asset theory underlines the important influence of technical factors on value and includes the concept of physical-asset specificity. This concept states that the more standardized a vehicle is with respect to technical features, the higher the resale potential and its market value. Theory and practice in aircraft and ship valuation support the relevance of technical features. Within the rail industry, there is consensus about the influence of technical features on value, as older vehicles with similar specifications as new vehicles can compete on a fairly similar level in the market. Furthermore, the presence of (multiple) train protection systems – which have a high share in the overall vehicle value – is considered important. Not only do such technical features have a direct effect on value, but also indirect effects through a higher resale potential. Also, the influence of the technical condition on vehicle value is widely acknowledged in rail and other markets. However, it is often difficult to include, so a normal state of the vehicle is assumed.

3: DETERMINANTS OF RAIL ROLLING STOCK VALUE

"Daten in der richtigen Qualität sind die Herausforderung…"

Johannes Max Theurer, CEO, Plasser & Theurer

(DVV Media Group GmbH | Eurailpress, 2016)

3.1 OVERVIEW OF POSSIBLE DETERMINANTS

Based on the knowledge acquired in Chapter 2 about the influence of the five broad explanatory factors (i.e. *Sectors, Age, Capacity, Earnings and Features*) on the value of moving assets, an overview can be made of possible determinants of rail vehicle value. Basing these overviews merely on Chapter 2 does not create a full picture of all possible determinants, as variables specific for rail vehicles are also included. Additional possible determinants are deduced from the collected transactional and technical data. Two separate overviews are made: one for locomotives and one for freight wagons. Section 3.2 explains the reason for scoping back to these two vehicle groups.

3.1.1 LOCOMOTIVES

Besides variables common for all general vehicle sectors, there are also variables specific to the individual sectors. Table 11 presents the variables as collected in the dataset categorized by their corresponding broad explanatory factors. These variables are further explained in Appendix A2.

TABLE 11: OVERVIEW OF VARIABLES - LOCOMOTIVES

SECTORS	AGE	CAPACITY	EARNINGS	FEATURES	OTHER
Sector	Year of deal	-	Performance freight market (billion tonne-kilometres)	Gauge (mm)	Manufacturer
	Year built		Performance pax market (billion passenger-kilometres)	Axle arrangement	Configuration
	Age			Propulsion system	Revision?
				Power rating primary (kW)	
				Power rating secondary (kW)	
				Emission compliance	
				Voltage system (kV)	
				Speed (km/h)	
				ETCS (Yes/No)	
				ETCS Level	

3.1.2 FREIGHT WAGONS

In a similar fashion as for locomotives, the variables for freight wagons are categorized according to the corresponding broad explanatory factors. Table 12 lists these factors and Appendix A3 further explains them.

Table 12: Overview of variables - Freight wagons

Sectors	Age	Capacity	Earnings	Features	Other
Sector	Year of deal	Cargo capacity (feet)	Performance freight market (billion tonne-kilometres)	Gauge (mm)	Manufacturer
	Year built	Cargo capacity (m^3)		Number of axles	Approval
	Age	Cargo capacity (tonne)		Speed loaded (km/h)	Revision?
		Loadable area (m^2)		Speed unloaded (km/h)	
				Tare weight (tonne)	
				Loadable width opening (mm)	
				Width bottom dump slides (mm)	
				Unloading system	
				Bogie type	
				Axle diameter (mm)	
				Brake type	

3.2 DATA COLLECTION, AVAILABILITY AND QUALITY

The collected transaction data has been retrieved from a variety of sources and includes a number of incomplete records of vehicle transactions. In many cases, it has been possible to find fill in missing values by means of further research into the vehicles in question.

3.2.1 DATA COLLECTION

The data has been sourced from the following sources:

- **Professional media and press releases**
  Railway Gazette International’s monthly overviews of rolling stock news, from February 2008 until October 2016, are the most important source. Other news related sources include press releases issued by rail vehicle producers, rail operators and lessors, as well as other professional railway media, including Eurailpress, Think Railways and Rynek Kolejowy.
- **Funds prospects**
  A second source of data comprises prospects and information of funds specialized in rail vehicle investments, including Paribus Capital (2015), DirektInvestment (2016) and SRI Rail Invest (2016).
- **Online market places**
  The third category of data sources comprises online marketplaces, such as DB Resale (2016), DB Gebrauchtzug (2016), Sterling Rail (2016) and VDMT (2016).
- **Industry insiders**
  Lastly, several industry insiders, who wish to remain anonymous (personal communication, 2016), have provided second-hand values.

In some cases, these sources mainly provided information about the transaction and the type of vehicle or did not contain any technical information or market-related information. Missing technical data has been complemented with information gathered from manufacturers or from the Lok-Datenbank.de (2016) rail vehicle database.

Data about the state of the rail freight and passenger rail markets is gathered from Eurostat. This European database provides the number of tonne-kilometres (Eurostat, 2016a) and the number of passenger-kilometres (Eurostat, 2016b) performed in the European Union, including other countries such as Switzerland, various Balkan states and Turkey. This data can be consulted in Appendix A4.

3.2.2 DATA AVAILABILITY

The availability of data about European rail vehicle sales has been of considerable influence in determining the scope of this research. In Chapter 2, six general sectors are identified for rail vehicles, namely locomotive, multiple unit/railcar, tram/LRV, metro, passenger coach and freight wagon. During the data collection process, six subsets have been created, one per sector, in anticipation of the data analysis phase. Also, it provided insight in the data availability per sector.

In general, the second-hand rolling stock market is large with an approximate 300 locomotives, 80 passenger wagons and 80 multiple units switching owner every year according to DVB Bank (Metz & Radstake, 2013). The yearly number of freight wagons traded on the second-hand market is unknown. The total investment in new vehicles per year is circa eight billion euros, spread over:

- 900 multiple units and rail cars
- 50 high speed trains
- 400 passenger coaches
- 800 locomotives
- 10,000 freight wagons

Of the six datasets, only for locomotives and freight wagons sufficient data was available. Despite a high number of transactions per year in Europe, most transactions and their details are not publicly available. Overall, 134 records containing values and technical information of locomotives are available, divided into 86 new vehicles and 48 used vehicles. With only six hybrid vehicles, it is not possible to draw valid conclusions for this group. It has been decided to exclude them ex-ante, leaving 128 records. As a result, also the variable *Power rating secondary* is deleted. For freight wagons, 103 records are available, of which 43 cases new and 60 second-hand vehicles.

For other vehicles, not enough data was available. In the case of multiple units and railcars, trams, metros and passenger wagons, data was mainly limited to new vehicles. To be able to draw robust conclusions about the relation between vehicle value and its determinants, this research limits itself to locomotives and freight wagons. In contrast to the respective investment and fleet sizes, more data was found for locomotives than for freight wagons. Partly, this is caused by lack of transparency in the freight wagon market due to high competition. Also, locomotive orders are publiced in the media more often for marketing purposes (e.g. large investments in more innovative vehicles).

3.2.3 DATA QUALITY

The original dataset contains records with not fully accurate and sometimes even missing values. Even though the data was entered with the utmost care, the data relies on the reliability of the source. Transactions with impossible transaction values (e.g. ten times higher than expected) have been filtered out beforehand. Some information provided anonymously by industry insiders or published in the media may be rounded for convenience or because it is sensitive information.

The original subset for new locomotives was fairly complete. Most missing data was related to whether a maintenance contract was included in the deal or not and, if so, for how long. Overall, only 10 out of 80 records included missing data on two closely related variables regarding the presence of a maintenance contract. Therefore, these two variables were excluded. Furthermore, three cases contained unconfirmed data with respect to emission compliance.

Data about second-hand locomotives was complete except for missing manufacturer names for two price indications of German V60 locomotives, built by various manufacturers. The share of unconfirmed values in this subset was higher than for new locomotives. Unconfirmed data was mainly related to the year of construction, especially for older locomotives, and power rating. The variable representing the year in which the vehicle had received its last revision contained many missing values (29 out of 48 cases) and was excluded. Also, various second-hand diesel locomotives lacked accurate values regarding emission compliance, so this variable was discarded.

The quality of the data for new freight wagons was very high. Out of 43 cases, none contained missing values. Unconfirmed values occurred mainly for the maximum width (5 cases) and maximum height (2 cases) of freight wagons, as well as for *Width bottom dump slides* (1 case), *Axle diameter* (1 case) and *Value* (4 cases).

For used freight wagons, the situation was different. Four out of sixty records contained missing values for fourteen different variables. They were excluded as it was impossible to recover any missing values with information of manufacturers or historical databases. Without these cases, the remaining missing values concentrated within the variable *Manufacturer*, making it a candidate for exclusion. Due to the high age of the wagons and incomplete transactional data, the manufacturer was impossible to recover. A fifth record involved a heavy-duty transporter for exceptional loads. Because of its specialized nature, it was excluded too. For most cases, it was unknown whether a maintenance contract was included in the deal or not and, if so, for how many years. Therefore, these two variables are excluded. The variable representing the year of revision was excluded too.

Data about the number of tonne-kilometres performed by rail freight operators in European countries (Eurostat, 2016a) was not available for every country for the period 2004-2016. This also was the case for the number of performed passenger-kilometres (Eurostat, 2016b). In both cases, countries with missing data (i.e. not available, confidential or not applicable) have been excluded, resulting in datasets comprising of 27 countries and 16 countries respectively. For rail freight, a dataset was obtained with no missing cases until 2014 and two missing cases in 2015, namely for Germany and Greece. For the year 2016, no data was known yet and thus an estimation for the annual growth in the period 2014-2019 by SCI Verkehr (2016c) has been used to estimate the missing values for 2015 and 2016. For the amount of passenger-kilometres, less data was available. As no annual growth estimation for further years was available, the average growth per annum for the period 2004-2015 has been used to estimate 2016 values.

Vehicles sold under exceptional circumstances (i.e. damaged, sold at auction or sold as part of a judicial sale) are excluded. En-bloc transactions are only included when all vehicles had the same specifications, making it possible to determine the value per vehicle. En-bloc transactions comprising of multiple vehicles with different specifications have been excluded. The result is a dataset with:

- 128 locomotive transactions
- 98 freight wagons transactions

According to Hair et al. (2009), these values lie between general guidelines of minimally 30 and maximally 1,000 observations for sufficient statistical power. Of course, the question may be asked if the ratio between the number of recorded transactions and the actual number of transactions over the period 2004-2016 is too small to classify the sample as representative for the entire population. On the one hand, this depends on the data distributions and to which extent these are in line with reality (Section 3.4). On the other hand, the available datasets benefit from a large amount of objectively measured variables and the high standardization in the rail sector, decreasing the number of systematic differences between vehicles in the sample and vehicles part of the population.

3.3 TRANSFORMATION TO USABLE DATA

The original datasets are not directly usable for analysis. Firstly, some variables require a transformation to suitable measurement scales. Secondly, some variables are only used to determine other variables. For example, the variables *Year of deal* and *Year built* are used to determine the age of the vehicles at the time of the transaction.

3.3.1 LOCOMOTIVES

A first variable to be transformed is the variable *Manufacturer*. Because for some vehicles the exact production location and/or country are not known (e.g. for so-called German 'Einheitslokomotiven' built by various manufacturers), the new variable *Manufacturer Sub-region* is created to overcome this issue. A differentiation is now made between Western and Eastern European producers.

In addition, the variable *Axle arrangement* is transformed, because of large variety in and overlap between axle arrangement designators. For example, Bo'Bo' and B'B' are both used for a four-axle diesel locomotive, but are propulsion dependent (i.e. Bo'Bo' for diesel-electric and B'B' for diesel-hydraulic or diesel-mechanic).

Further variables that are transformed are:

- ***Propulsion system***
  The variable *Propulsion system* is turned into three variables, namely *Traction type electric* (AC, DC, MS), *Traction type diesel* (De, Dh, Dm) and *Number of diesel engines*.
- ***Voltage system***
  To cope with the different combinations of voltage systems, *Voltage system* is transformed into the variable *Number of voltage systems* as a measure of technical flexibility.
- ***Configuration***
  Configuration is transformed into *Number of country approvals*, as an indicator of geographic flexibility.
- ***ETCS (Yes/No)* and *ETCS Level***
  The variables *ETCS (Yes/No)* and *ETCS Level* are replaced by *ETCS Category*, distinguishing: no ETCS (n/a), ETCS Level 1 equipment (L1) or ETCS Level 2 equipment (L2).

Table 13 lists the variables and their measurement scales.

TABLE 13: OVERVIEW OF FINAL VARIABLES - LOCOMOTIVES

VARIABLE	UNIT	MEASUREMENT SCALE
Age	Year	Ratio (Scale)
Index freight market	-	Ratio (Scale)
Index passenger market	-	Ratio (Scale)
Manufacturer Sub-region	-	Nominal
Sector	-	Nominal
Gauge	mm	Ratio (Scale)
Number of axles	-	Ratio (Scale)
Traction type electric	-	Nominal
Traction type diesel	-	Nominal
Number of diesel engines	-	Ratio (Scale)
Power rating primary	kW	Ratio (Scale)
Number of voltage systems	-	Ratio (Scale)
Number of country approvals	-	Ratio (Scale)
Speed	km/h	Ratio (Scale)
ETCS Category	-	Ordinal
Revision?	-	Nominal

3.3.2 FREIGHT WAGONS

Similar as for locomotives, several variables are transformed:

- ***Manufacturer***
  Manufacturer Sub-region replaces the variable *Manufacturer*, distinguishing Western and Eastern European producers.
- ***Type***
  Sector replaces *Type* and is based on the class of wagon as established in Chapter 2.
- ***Bogie type***
  Replaced by *Bogie family*, it is determined if wagon bogies belong to the Y25 family.
- ***Brake type***
  Lastly, *Brake family* replaces *Brake type* and lists if a wagon has Knorr type KE brakes, Oerlikon brakes or brakes from other families.

Table 14 list the variables and their measurement scales.

TABLE 14: OVERVIEW OF FINAL VARIABLES - FREIGHT WAGONS

VARIABLE	UNIT	MEASUREMENT SCALE
Age	Year	Ratio (Scale)
Index freight market	-	Ratio (Scale)
Manufacturer Sub-region	-	Nominal
Sector	-	Nominal
Gauge	mm	Ratio (Scale)
Approval	-	Nominal
Number of axles	-	Ratio (Scale)
Speed loaded	km/h	Ratio (Scale)
Speed unloaded	km/h	Ratio (Scale)
Tare weight	kg	Ratio (Scale)
Cargo capacity feet	feet	Ratio (Scale)
Cargo capacity m^3	m^3	Ratio (Scale)
Cargo capacity tonnes	tonne	Ratio (Scale)
Loadable area	m^2	Ratio (Scale)
Loadable width opening	mm	Ratio (Scale)
Width bottom dump slides	mm	Ratio (Scale)
Unloading system	-	Nominal
Bogie family	-	Nominal
Axle diameter	mm	Ratio (Scale)
Brake family	-	Nominal
Revision?	-	Nominal

3.4 DATA OVERVIEW AND DISTRIBUTIONS

The first step to provide more insight in the collected data is looking at the descriptive statistics of the datasets. This is done by presenting the data distributions and correlations of the variables.

3.4.1 LOCOMOTIVES

Table 15 gives a first overview of metric variables. Locomotive values vary between €3,000 and €5,000,000, with an average of €1,895,000. *Age* has a low average of 14.8 years, given a maximum of 76 years. *Index freight market* has a relatively low average compared to its minimum and maximum, but the values for *Index passenger market* vary quite well. Compared to standard gauge (1435 mm), the average of the variable *Gauge* indicates that the dataset contains more broad gauge than narrow gauge locomotives. For the variable *No. of axles*, the values match the expectations.

The *Number of diesel engines* ranges from 0 to 4, with an average value of 1. The *Power rating primary* has a well-positioned, but relatively low, average. *Number of voltage systems* has a natural minimum value of 0 and a maximum of 4, which is the maximum for multisystem electrics. Overall, the average value of 1 corresponds with the situation in the market, in which multisystem electrics equipped for three or four voltage systems are still upcoming and locomotives for domestic services are dominant. This is reflected in a high maximum value for the variable *Number of country approvals* and the low average of 1. The minimum value of 0 reflects locomotives that are not allowed on national networks anymore and/or built for internal rail systems at workshops or industrial sites. The variable *Speed* has a well-positioned average compared its minimum and maximum values.

TABLE 15: DATA OVERVIEW METRIC VARIABLES - LOCOMOTIVES

VARIABLE	MINIMUM VALUE	AVERAGE VALUE	MAXIMUM VALUE	NUMBER OF CASES
Value (x€1,000)	3.0	1,895.0	5,000.0	128
Age	0	14.8	76	128
Index freight market	89.3	101.9	109.4	128
Index passenger market	100.0	114.9	124.7	128
Gauge (mm)	1,000	1,446	1,668	128
Number of axles	2	4	6	128
Number of diesel engines	0	1	4	128
Power rating primary (kW)	28	2,555	6,600	128
Number of voltage systems	0	1	4	128
Number of country approvals	0	1	8	128
Speed (km/h)	15	115.0	230	128

Table 16 presents the distribution of the non-metric variables *Manufacturer sub-region*, *Sector* and *Revision?* Most locomotives have been built in Western Europe and none outside Europe. More than 75% of the locomotives are mainline locomotives and almost 80% of the locomotives circulated in a valid maintenance regime when the transaction took place.

TABLE 16: DATA OVERVIEW NON-METRIC VARIABLES - LOCOMOTIVES - PT. 1

MANUFACTURER SUB-REGION	%	SECTOR	%	REVISION?	%
Eastern Europe	20.3	**Mainline**	76.6	**No**	21.9
Western Europe	79.7	**Shunter**	23.4	**Yes**	78.1

Table 17 shows that with 64.8% the majority of the locomotives is diesel-powered. For *Traction type electric,* it becomes clear that AC and DC traction installations form the bulk of the electric traction installations. *Traction type diesel* shows that the most common types are diesel-electric (De) and diesel-hydraulic (Dh). Diesel-mechanic (Dm) is in the minority with 7.8%. Most locomotives are not equipped with ETCS. Of the locomotives that are, most have a Level 2 system.

TABLE 17: DATA OVERVIEW NON-METRIC VARIABLES - LOCOMOTIVES - PT. 2

PROPULSION CATEGORY	%	TRACTION TYPE ELECTRIC	%	TRACTION TYPE DIESEL	%	ETCS CATEGORY	%
Diesel	64.8	**AC**	14.1	**De**	32.8	**n/a**	94.5
Electric	35.2	**DC**	12.5	**Dh**	24.2	**L1**	0.8
		MS	8.6	**Dm**	7.8	**L2**	4.7
		n/a	64.8	**n/a**	35.2		

Not further considered in this thesis are: *Traction type electric* and *Traction type diesel*. The available data does not allow many detailed variables with a sample size of 128 cases. Therefore, this thesis limits itself to a general distinction of electric and diesel locomotives.

3.4.2 FREIGHT WAGONS

For freight wagons, the initial descriptive statistics of the metric variables are presented in Table 18. On first sight, the average wagon value is quite low. The variables *Age* and *Performance freight market* show good variance between their minimum and maximum values. Compared to *Speed* *unloaded*, the average of *Speed loaded* is relatively low, indicating most wagons are restricted to run under s-regime (≤100 km/h) when loaded.

Tare weight, *Cargo capacity (feet)*, *Cargo capacity (m*^{3}*)*, *Cargo capacity (tonnes)*, *Cargo capacity general (tonnes)* and *Loadable area (m*^{2}*)* are all spread well between their minimum and maximum values. The average value of *Loadable width opening* is relatively high in relation to its minimum and maximum values. *Width bottom dump slides* has a low average of 2,797 mm considering the minimum value of 500 mm and maximum value of 10,039 mm. With 918 mm, the average *Axle diameter* corresponds with the most widely used diameter of 920 mm.

Table 18: Data overview metric variables - Freight wagons

Variable	Minimum value	Average value	Maximum value	Number of cases
Value (x€1,000)	3.33	57.36	320.00	98
Age	0	17	58	98
Performance freight market (index)	367.7	420.7	443.3	98
Gauge (mm)	1,435	1,435	1,435	98
No. of axles	2	4	6	98
Speed loaded (km/h)	100	103	120	98
Speed unloaded (km/h)	100	116	120	98
Tare weight (tonne)	10.0	22.3	38.0	98
Cargo capacity (feet)	30	66	90	98
Cargo capacity (m^3)	16	71	168	98
Cargo capacity (tonne)	34.4	63.5	105.6	98
Cargo capacity general (tonne)	15.0	58.6	108.8	98
Loadable area (m^2)	24	41	63	98
Loadable width opening (mm)	600	2,115	3,000	98
Width bottom dump slides (mm)	500	2,797	10,039	98
Axle diameter (mm)	730	918	1,000	98

Table 19 shows that nearly 70% of the wagons has been built in Eastern Europe and the remainder in Western Europe. It is also apparent that most of the wagons are dry bulk wagons (41.8%), followed by intermodal wagons (19.4%) and break-bulk wagons (16.3%). All wagons have RIV / TEN approval, so this variable is discarded. The majority of the freight wagons was in a valid maintenance regime.

Table 19: Data overview non-metric variables - Freight wagons - Pt. 1

Manufacturer sub-region	%	Sector	%	Approval	%	Revision?	%
Eastern Europe	69.4	**Break-bulk**	16.3	**RIV / TEN**	100.0	**No**	22.4
Western Europe	30.6	**Cars**	2.0			**Yes**	77.6
		Coils/plates	8.2				
		Dry bulk	41.8				
		Intermodal	19.4				
		Liquid bulk	12.2				

Table 20 shows that the distribution of the different unloading systems is nearly fifty-fifty. With respect to the *Bogie family*, 26.5% of the wagons does not have bogies and 4.1% of the wagons has bogies that not belong to the standardized Y25 family. For the variable *Brake family*, a high percentage of nearly 75% can be witnessed for Knorr brakes, Oerlikon follows with 18.4% and other manufacturers have a mere share of 7.1% in the dataset.

Table 20: Data overview non-metric variables - Freight wagons - Pt. 2

Unloading system	%	Bogie family	%	Brake family	%
Manual / mechanic	17.3	**n/a**	26.5	**Knorr**	74.5
Pneumatic	15.3	**Y25**	69.4	**Oerlikon**	18.4
n/a	67.4	**Other**	4.1	**Other**	7.1

Some variables are not further considered in this thesis. With 98 cases, it is not possible to come to valid conclusions when going into too much detail. For the capacity indicators, as established in Chapter 2, the general cargo capacity is a suitable alternative, so the sector-specific capacity indicators are excluded. Additionally, the loadable width of the opening of bulk wagons and the width of their bottom dump slides have been discarded, as they apply to a small number of cases. Of the non-metric variables, the variable *Unloading system* is discarded for the same reason.

3.5 EXPECTED INFLUENCE OF EXPLANATORY FACTORS ON VALUE

Prior to performing further quantitative analyses, the expected signs of the relations between explanatory factors and value needs to be set out. This way, it can be checked whether positive or negative coefficients meet these expectations. A short background of the expected coefficient sign is included per variable, based on the established theory in Chapter 2.

3.5.1 LOCOMOTIVES

The expected coefficient signs for locomotives are listed in Table 21.

TABLE 21: EXPECTED COEFFICIENT SIGNS - LOCOMOTIVES

VARIABLE	SIGN COEFFICIENT	REMARK
Age	-	The higher a vehicle's age, the lower its value
Index freight market	+	A higher transport demand results in a higher demand for transport means and higher demand increases price through scarcity
Index passenger market	+	A higher transport demand results in a higher demand for transport means and higher demand increases price through scarcity
Gauge	+	Vehicle size increases with gauge size, resulting in higher prices/value. Standard and broad gauge are more common than narrow gauge, meaning a larger the potential second-hand market
Number of axles	+	The more axles, the larger the vehicle, the higher its price/value
Power rating primary	+	The more powerful a vehicle, the higher its price/value
Number of countries	+	The more country approvals, the higher the flexibility in use and the larger the potential second-hand market, boosting value
Speed	+	A higher maximum speed results in a higher value for technical reasons. Lower speeds decrease operational flexibility, resulting in lower prices
Number of diesel engines	+	Locomotives with multiple diesel engines house more complex technology and offer more operational benefits, resulting in higher values
Number of voltage systems	+	Not only additional electrical equipment, but also increased operational flexibility and a larger second-hand market boost prices/values
Manufacturer sub-region	-	Considering Western Europe as the reference category, vehicles built in Eastern Europe are priced/valued lower thanks to lower labour costs
Sector	-	Considering mainline locomotives as the reference category, shunters are expected to be valued lower. A larger second-hand market may offset this
Revision?	-	Considering a vehicle in valid revision regime as the reference category, vehicles that are not are valued lower
Propulsion category	+	Considering diesel as the reference category, technically more complex electric locomotives are valued higher
ETCS category	+	Considering no ETCS on board as the reference category, ETCS equipment on its own adds to vehicle value, as well as the resulting increased operational flexibility with every level

3.5.2 FREIGHT WAGONS

The expected coefficient signs for freight wagons are listed in Table 22.

TABLE 22: EXPECTED COEFFICIENT SIGNS - FREIGHT WAGONS

VARIABLE	SIGN COEFFICIENT	EXPECTATION
Age	-	The higher a vehicle's age, the lower its value
Index freight market	+	A higher transport demand results in a higher demand for transport means and higher demand increases price through scarcity
Number of axles	+	The more axles, the larger the vehicle, the higher its price/value
Speed loaded	+	A higher maximum speed results in a higher value for technical reasons. Lower speeds decrease operational flexibility, resulting in lower prices
Speed unloaded	+	A higher maximum speed results in a higher value for technical reasons. Lower speeds decrease operational flexibility, resulting in lower prices
Tare weight	-	A higher tare weight, normally results in a lower capacity, resulting in lower vehicle values
Capacity general	+	A higher wagon capacity, results in higher vehicle values
Axle diameter	+	Higher axle diameters often allow for higher operational speeds, increasing vehicle value
Manufacturer sub-region	-	Considering Western Europe as the reference category, vehicles built in Eastern Europe are priced/valued lower thanks to lower labour costs
Sector	+	Considering dry bulk wagons as the reference category, technically more complex wagons (break-bulk, cars, coils/plates, intermodal and liquid bulk) are valued higher
Revision?	-	Considering a vehicle in valid revision regime as the reference category, vehicles that are not are valued lower
Bogie family	+	Considering a vehicle without bogies as the reference category, wagons with Y25 or other, more specialized, bogies have higher values
Brake family	+	Considering the widely used Knorr system as the reference category, more specialized braking systems have higher values

3.6 CORRELATIONS

This section gives an overview of the correlations for locomotives and freight wagons. Listing the correlations between variables provides a starting point for the setup of the regression model, as they give a first indication of the strength of the relationship between two variables. Strong correlations, higher than 0.4, are marked in bold. Very strong correlations may hint at (multi)collinearity, which is to be prevented in the model. The tables list the 1-tailed correlations for metric variables only, as the direction of the relationship is known for all variables. The dependence of value on non-metric variables is researched in Section 4.2, using multiple regression in a trial and error approach, during which the model is gradually expanded with non-metric variables.

3.6.1 LOCOMOTIVES

Table 23 presents strong and significant correlations with *Value* for the following variables:

- *Age*
- *Index passenger market*
- *Power rating primary*
- *Number of countries*
- *Speed*
- *Number of voltage systems*

Other significant, but less strong, correlations exist for the variables:

- *Gauge*
- *Number of axles*
- *Number of diesel engines*

Surprisingly, *Index freight market* is not of influence and *Index passenger market* has a negative sign. Demand for rail transport grew and one would expect that the demand for vehicles follows this development, resulting in higher selling prices. The negative correlation may have to do with relatively low prices per vehicle because of large transactions registered in years when the market was weak. Furthermore, it may have to do with the increasing role of multiple units in passenger rail transport at the cost of locomotives.

Not surprisingly, another strong positive correlation exists between *Number of countries* and *Power rating primary*, as multisystem locomotives with multiple country approvals tend to have high power ratings. In addition, the number of countries in which diesel locomotives can operate is often restricted. Not only due to fuel capacity, but also because a large share of the railway lines in Europe is electrified which makes long-haul diesel operations economically uninteresting. This is also deduced from the positive relation between *Number of voltage systems* and *Power rating primary*, and between *Number of voltage systems* and *Number of countries*.

Table 23: Correlations - Locomotives

	Value	Age	Index freight market	Index passenger market	Gauge	Number of axles	Power rating primary	Number of countries	Speed	Number of diesel engines	Number of voltage systems
Value	1										
Age	**-.735****	1									
Index freight market	.038	.038	1								
Index passenger market	**-.539****	**.642****	.024	1							
Gauge	.212**	-.176*	.189*	-.272**	1						
Number of axles	.270**	-.301**	-.027	-.285**	.303**	1					
Power rating primary	**.727****	-.399**	.039	-.338**	.083	.365**	1				
Number of countries	**.555****	-.312**	.095	-.290**	-.070	.215*	**.649****	1			
Speed	**.756****	**-.542****	.029	**-.407****	.038	**.452****	**.794****	**.581****	1		
Number of diesel engines	-.220*	.085	-.061	.164	-.016	-.054	**-.584****	-.359**	-.324**	1	
Number of voltage systems	**.583****	-.267**	.169*	-.289**	-.034	.018	**.772****	**.775****	**.644****	**-.605****	1

** Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at the 0.05 level (1-tailed).

Also expected: a strong positive correlation between *Speed* and *Power rating primary*, as well as between *Speed* and *Number of countries*. A negative correlation is witnessed between *Number of diesel engines* and *Power rating primary*, as expected because diesel locomotives tend to have lower power ratings than electrics. The relatively strong positive correlation between *Number of voltage systems* and *Speed* is not surprising, as electrics tend to have higher maximum speeds than diesel locomotives, which are mostly used for slower freight trains. As expected, negative correlation exists between *Number of voltage systems* and *Number of diesel engines*, and between *Speed* and *Index passenger market*. Positive correlation exists between *Index passenger market* and *Age*.

3.6.2 Freight wagons

Table 24 presents the correlations as found for freight wagons. A strong negative correlation between the variables *Age* and *Value* exists, as expected. Further significant relations with *Value* exist for the variables:

- *Number of axles*
- *Speed loaded*
- *Speed unloaded*
- *Tare weight*
- *Capacity general*

Of these variables, *Speed loaded* the relation with *Value* is weaker than for the other variables. A relationship between *Index freight market* and *Value* is not discovered, similar to locomotives. The sign of these relations is as expected. Interestingly, there is a negative, but not significant, relation between A*xle diameter* and *Value*. This may indicate that axle diameters greater than the industry average of 920 millimetres are considered non-standard, which has a negative influence on *Value*.

Table 24: Correlations - Freight wagons

	Value	Age	Index freight market	Number of axles	Speed loaded	Speed unloaded	Tare weight	Capacity general	Axle diameter
Value	1								
Age	**-.685****	1							
Index freight market	.013	.085	1						
Number of axles	**.481****	**-.549****	-.026	1					
Speed loaded	.299**	-.356**	.124	.334**	1				
Speed unloaded	**.421****	**-.590****	-.063	**.622****	.233*	1			
Tare weight	**.648****	**-.541****	.057	**.830****	.265**	**.578****	1		
Capacity general	**.509****	**-.636****	-.038	**.941****	**.420****	**.609****	**.720****	1	
Axle diameter	-.168	.136	-.036	-.089	.039	-.028	-.166	.041	1

** CORRELATION IS SIGNIFICANT AT THE 0.01 LEVEL (1-TAILED). * CORRELATION IS SIGNIFICANT AT THE 0.05 LEVEL (1-TAILED).

Strong negative correlations exist between:

- *Number of axles* and *Age*, representing the dominance of four- and six-axle designs among modern wagons
- *Speed* unloaded and *Age*, representing the increased maximum speed of newer wagons.
- *Tare weight* and *Age*, and *Capacity general* and *Age*. This is in line with the previously mentioned trend. The strong correlation with *Number of axles* supports this. Altogether, this indicates that these variables should be handled with care when building the model due to possible multicollinearity.

3.7 Ex-ante visual linearity check

Although a more elaborate check for linearity of the model and the relationships between the explanatory variables and vehicle value is performed post-hoc. This section summarizes the most important findings; the visual analysis using scatterplots of the independent variables versus *Value* is included in Appendix A5.

3.7.1 LOCOMOTIVES

The assumption of linearity holds quite well for most metric explanatory factors. For locomotives, the most important observations are as follows:

- *Index freight market* and *Index passenger market* do not show signs of a linear relationship with value. In fact, the random pattern in the observations does not hint at any relationship at all.
- Linearity of the relationship between *Power rating primary* and *Value* may be questioned at first sight. However, as the data distributions in Section 3.4.2 support, fewer observations for high-powered second-hand vehicles than for new vehicles seem to be the cause. With the data available. Despite this, the linear line seems to connect the most important concentrations of observations fairly well and the assumption of linearity is considered to hold sufficiently.
- A negative relationship between *Number of diesel engines* and *Value* is calculated, but the true nature of the relationship is doubtful.

3.7.2 FREIGHT WAGONS

For freight wagons, the assumption of linearity holds for most variables too. The most important observations are as follows:

- Despite linearity not being an issue, there does not appear to be a relationship between *Index freight market* and *Value.*
- The large number of observations around the standard axle diameter of 920 mm make the nature of the relationship more difficult to determine. However, the outlying observation of a high-value car transporter is no rarity. Car transporters and wagons for 'Rollende Landstrasse' operations generally have smaller diameters but higher values. Despite the high uncertainty, linearity is considered fully appropriate.

3.8 CONCLUSIONS

3.8.1 DATA AVAILABILITY, QUALITY AND DISTRIBUTIONS

Formulated in Chapter 1, research question I states:

"How frequent are sale and purchase transactions for rail rolling stock? Is the size of the market sufficiently large and does it provide sufficiently available data of a satisfactory quality for a reliable application of more automated valuation techniques?"

Sufficient transaction data for a representative sample is only available for locomotives and freight wagons, other vehicles are outside the scope of this thesis. In 2013, the total yearly investment in new rail vehicles in Europe amounted circa eight billion euros. Amongst other new vehicles, this includes:

- circa 800 locomotives
- circa 10,000 freight wagons

Yearly, around 80 locomotives are sold on the second-hand market. The yearly number of freight wagons changing owners is unknown, but compared with the ratios between other types of rail vehicles this is expected to be 10-20% of the number of new freight wagons.

It is essential to have enough representative data of a sufficiently high quality. The available data includes:

- 128 locomotives
- 98 freight wagons

Although seemingly small compared to the size of the market, these values lie between general guidelines of minimally 30 and maximally 1,000 observations for sufficient statistical power. The question may be asked if the ratio between the number of recorded transactions and the actual number of transactions over the period 2004-2016 is too small to classify the sample as representative for the entire population.

On the one hand, this depends on and to which extent these are in line with reality. The first descriptive statistical analyses performed on the available datasets show that for both locomotives and freight wagons the variable values vary quite well. Some variables are slightly skewed, but this is not expected to form a problem.

On the other hand, the available datasets benefit from a large amount of objectively measured variables and the high standardization in the rail sector, decreasing the number of systematic differences between vehicles in the sample and vehicles part of the population. Furthermore, special vehicles with extraordinary parameter values are not included.

The available data enables the estimation of parsimonious models, keeping a preferred ratio between 1:15 and 1:20 in mind between the number of explanatory variables and the number of cases available. The drawback is that highly detailed models with many (group-)specific variables cannot be estimated and power is reduced.

Overall, despite the relatively small datasets, both samples are considered sufficiently representative for the total locomotive (i.e. regular electric and diesel) and standard freight wagons.

3.8.2 CORRELATIONS

The correlations between the different explanatory variables and vehicle value – but also between the different explanatory variables themselves – correspond largely with what one would expect with respect to the theoretical and practical basis as established in Chapter 2. This includes the presence of high correlations between certain variables, especially for freight wagons. They warn for possible multicollinearity and require attention when setting up the regression models.

Based on the broad explanatory factors determined in Chapter 2 and the data available, a set of specific metric variables is established for a correlation analysis. The considered variables are listed per vehicle type and by their corresponding broad explanatory factors. The variables with the strongest, significant correlations with *Value* are in bold with the corresponding correlation coefficient in brackets. These variables provide a starting point for the specification of the regression models. Additionally, the most important remarks regarding the outcomes of the correlation analysis are reported.

LOCOMOTIVES

The considered variables and the strongest observed correlations are:

- *Age*
    - ***Age (-.735)***
- *Earnings*
    - *Index freight market*
    - ***Index passenger market (-.539)***
- *Technical features*
    - *Gauge*

    - *Number of axles*
    - ***Power rating primary (.727)***
    - ***Speed (.756)***
    - *Number of diesel engines*
    - ***Number of voltage systems (.583)***
- *Other*
    - ***Number of countries (.555)***

The following remarks can be made with respect to the outcomes:

- *Index freight market – Value* not (directly) of influence
- *Index passenger market - Value* has a surprising, but not impossible, negative coefficient. Other relations are as expected
- Strong relations between independent variables, which may hint at multicollinearity, exist for:
    - *Number of countries* and *Power rating primary*
    - *Number of diesel engines* and *Power rating primary*
    - *Number of voltage systems* and *Number of countries, Number of diesel engines, Power rating primary, Speed*
    - *Speed* and *Index passenger market, Number of countries, Power rating primary*

FREIGHT WAGONS

The considered variables and the strongest observed correlations are:

- *Age*
    - ***Age (-.685)***
- *Capacity*
- *Earnings*
    - *Index freight market*
- *Technical features*
    - ***Number of axles (.481)***
    - *Speed loaded*
    - ***Speed unloaded (.421)***
    - ***Tare weight (.648)***
    - ***Capacity general (.509)***
    - *Axle diameter*

However, the following is to be considered:

- A direct relationship between *Index freight market* and *Value* is not found
- The sign of the relations is as expected
- Strong relations between independent variables, which may hint at multicollinearity, exist for:
    - *Age* and *Number of axles, Speed unloaded*, *Tare weight*, *Capacity general*
    - *Number of axles* and *Speed unloaded*, *Tare weight*, *Capacity general*
    - *Capacity general* and *Speed loaded*, *Speed unloaded*, *Tare weight*
    - *Tare weight* and *Speed unloaded*

3.8.3 LINEARITY

Furthermore, it is established that the assumption of linearity holds reasonably well for most variables. However, the market variables *Index freight market* and *Index passenger market* are an exception. These two variables do not show any signs of a specific relationship with *Value*. The randomness in the observations do not make linearity an issue, but no relationship is expected to be found in Chapter 4.

4: LINEAR MODEL SPECIFICATION AND RESULTS

"Today, innovation in the rail industry primarily means innovation in digitalisation…"

Jochen Eickholt, CEO, Siemens Mobility

(Eickholt, 2016)

In this chapter, a step forward is done from the first statistical findings in Chapter 3. With the use of IBM Software's SPSS 24, it combines these findings and the theory established in Chapter 2 in multivariate regression models. There is a possibility to include non-metric variables by using dummy variables, enabling the inclusion of a broad variety of variables, both economic and technical. The coding scheme of these variables and their reference categories are included in Appendix A6.

All the outcomes are calculated using the standard SPSS significance level of 0.05. Because the number of cases is sufficient but limited, the power is not very strong, relations between variables have to be fairly strong to become significant. This increases the risk of discarding relationships between variables that do actually exist in reality and which may be found if more cases are available for analysis. As the nature of the relationship is known for the variables, a one-sided test would mean that a value of 0.10 would be significant, resulting in more variables being included. However, besides adding more variables to overcome this issue, this also increases the chance of wrongly concluding an effect is significant, whilst it is not in reality (from 5% tot 10%). In this case, the researcher prefers a more parsimonious and conservative approach over an increased risk of wrongly concluding certain relationships actually exist and decrease generalizability of the results.

4.1 WORKING TOWARDS A MODEL: LOCOMOTIVES

The modelling process commences with gaining insight into the influence of a basic set of determinants on value. Gradually, this base model is expanded manually to a more comprehensive model until the increase in the value of the adjusted coefficient of determination (adjusted R^2) becomes so small that adding additional variables is not worthwhile.

Manually extending the models in this fashion has multiple goals:

- to ensure the inclusion of variables of different natures, from technical to economical, that should be added according to the theory as established in Chapter 2 and the preliminary findings in Chapter 3; and
- to give insight in the individual effects that adding or excluding the various variables has on the model results; as well as
- to determine possible existence of multicollinearity between the included variables.

Finally, the results of these handcrafted models are compared to those of models created with the automatic Stepwise function of SPSS. This function adds those variables that have the strongest relation with vehicle value, but may not return a model that fully respects the desired theoretical outlines. A certain extent of multicollinearity may still be present in these automatically created models. However, as an implicit aim of modelling is to create parsimonious models, it is checked to what extent this automated approach offers simpler models that combine the requirements set out above with good – and preferably better – explanatory power. The intermediate, handmade, models are not discussed here, but give the reader insight in the effects of adding individual variables.

4.1.1 MODEL SPECIFICATION

Eight models are specified by the researcher, starting with a combination of *Age*, a market related variable and a technical variable. Subsequently, this model is expanded step-by-step. First, the metric variables are added, for which Chapter 3 has provided a good starting point, followed by the non-metric variables. Throughout the modelling process, some variables are excluded again when not significant or when showing multicollinearity. The following variables are added in the following sequence:

- Model 1: *Age, Index passenger market, Power rating primary*
- Model 2: *Speed*
- Model 3: *Number of countries*
- Model 4: *ETCS L1, ETCS L2*
- Model 5: *No revision*
- Model 6: *Manufacturer Eastern Europe*
- Model 7: *Electric propulsion*
- Model 8: *Sector shunter*

Models 9 and 10 are specified with the Stepwise function and see the following variables added:

- Model 9: *Age, Power rating primary, Speed, ETCS L2, Manufacturer Eastern Europe, Sector shunter*
- Model 10: *Gauge*

The full model specifications, including a more elaborate discussion of the considerations for adding and excluding variables during the modelling process is included in Appendix A7.

4.1.2 RESULTS

This section gives an overview of the results of the models specified in Section 4.2.1 and discusses the results of Models 9 and 10 in order to make a choice for a final model. Models 1-6 are listed in Table 25, Models 7-10 in Table 26. Collinearity statistics for all models are included in Appendix A8 and the full results for the final model in Appendix A9.

TABLE 25: LOCOMOTIVES (LINEAR) - RESULTS - PT. 1

MODEL	**1**		**2**		**3**		**4**		**5**		**6**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**
Age	-.503	.000	-.478	.000	-.476	.000	-.470	.000	-.371	.000	-.423	.000
Index passenger market	-.043	.458	---	---	---	---	---	---	---	---	---	---
Power rating primary	.512	.000	.384	.000	.344	.000	.364	.000	.390	.000	.352	.000
Speed			.192	.000	.179	.022	.193	.012	.170	.023	.185	.008
Number of countries					.080	.160	---	---	---	---	---	---
Non-metric												
ETCS L1							-.012	.775	---	---	---	---
ETCS L2							.107	.015	.104	.015	.103	.009
No revision									.-141	.018	-.104	.060
Manufacturer Eastern Europe											-.183	.000
N	128		128		128		128		128		128	
Adj. R²	75.9%		77.0%		77.2%		77.8%		78.7%		81.9%	

When looking at Model 8, the last model specified manually based on the findings in Chapter 2 and 3, we see a model that explains 82.3% of the variance in locomotive value. This is the best result compared with previous models, but the model still includes variables that are not significant.

Cleaning up Model 8 by filtering out only the strongest relationships with the Stepwise function, results in a six-variable model (Model 9) covering the broad explanatory factors *Sector*, *Age* and *Technical features,* as well as a rail specific variable. Although supported by literature, *Number of countries* and *No revision* lack. Not surprisingly, *No revision* is excluded, as its significance gradually decreases from Model 6 onwards. Overall, the Adjusted R^2 value is still good with 82.1% and the model covers a good variety of different variables, while respecting model parsimony.

For Model 10, also built with the Stepwise function, all possible metric determinants are considered again. This expands Model 9 with *Gauge*, which has a significant positive relation with value. So the broader the gauge, the higher a locomotive's value. This relation is as anticipated, as narrow gauge railways are relatively rare compared to standard and broad gauge railway systems. Therefore, the latter can be remarketed more easily.

TABLE 26: LOCOMOTIVES (LINEAR) - RESULTS - PT. 2

MODEL	**7**		**8**		**9**		**10**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**B**	**Sig.**	**β**	**Sig.**
Age	-.420	.000	-.456	.000	-.519	.000	-.495	.000
Index passenger market	---	---	---	---	---	---	---	---
Power rating primary	.408	.000	.338	.000	.320	.000	.296	.000
Speed	.182	.009	.267	.001	.293	.000	.337	.000
Number of countries	---	---	---	---	---	---	---	---
Gauge	---	---	---	---	---	---	.119	.002
Non-metric								
ETCS L1	---	---	---	---	---	---	---	---
ETCS L2	.100	.011	.100	.010	.102	.010	.112	.003
No revision	-.098	.082	-.084	.132	---	---	---	---
Manufacturer Eastern Europe	-.177	.000	-.171	.000	-.177	.000	-.175	.000
Electric propulsion	-.061	.402	---	---	---	---	---	---
Sector shunter			.110	.067	.128	.031	.154	.008
Interaction electric propulsion and sector					---	---	---	---
N	128		128		128		128	
Adj. R^2	81.9%		82.3%		82.1%		83.3%	

The adjusted R^2 is 83.3%, the highest result up until now. This is reasonable, as the model is not to explain value precisely. There is always an error, because of specific considerations during the transaction, influencing the final transaction value. For example, condition related influences and external influences such as spare part availability. Moreover, minor data errors, for example caused by rounding values for reasons of convenience or for confidentiality and typing errors in publication, remain possible. Lastly, the effects of the state of the market on price levels are not fully covered, as such indicators are not included. Nonetheless, Model 10 is the model of choice for now.

4.2 WORKING TOWARDS A MODEL: FREIGHT WAGONS

The modelling process for freight wagons is largely similar as for locomotives.

4.2.1 MODEL SPECIFICATION

Eight models are specified by the researcher, with the base model again combining *Age* with a market related variable and a technical variable. Subsequently, this model is expanded step-by-step., but there is a key difference with the approach used for locomotives. Due to the large number of high correlations between the various metric technical variables, these are collectively added in the second step to identify problematic cases of multicollinearity. After this, the approach is similar again and first sees the addition of metric variables, for which Chapter 3 has provided a good starting point, followed by the non-metric variables. Throughout the process, variables are excluded again when not significant or in case of multicollinearity. The following variables are added in the following sequence:

- Model 1: *Age, Index freight market, Capacity general*
- Model 2: *Number of axles*, *Speed loaded*, *Speed unloaded*, *Tare weight*, *Axle diameter*
- Model 3: n/a
- Model 4: *Bogie family Y25*, *Bogie family other*
- Model 5: *Brake family Oerlikon*, *Brake family other*
- Model 6: *No revision*
- Model 7: *Manufacturer Eastern Europe*
- Model 8: *Sector liquid bulk*, *Sector break-bulk*, *Sector intermodal*, *Sector coils/plates*, *Sector cars*

For Models 9 and 10, the Stepwise function is used. This sees the following variables added:

- Model 9: *Age*, *Capacity general*, *Number of axles*, *Tare weight*, *Axle diameter*, *Brake family other*, *No revision*, *Sector cars*
- Model 10: *Sector break-bulk*

The full model specifications, including a more elaborate discussion of the considerations for adding and excluding variables during the modelling process is included in Appendix A7.

4.2.2 RESULTS

This section gives an overview of the results of the models specified in Section 4.3.1 and discusses the results of Models 8, 9 and 10 in order to make a choice for a final model. Models 1-5 are listed in Table 27, Models 6-10 in Table 28. Collinearity statistics for all models are included in Appendix A8 and the full results for the model of choice in Appendix A9.

TABLE 27: FREIGHT WAGONS (LINEAR) - RESULTS - PT. 1

MODEL	**1**		**2**		**3**		**4**		**5**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**
Age	-.614	.000	-.417	.000	-.523	.000	-.530	.000	-.498	.000
Index freight market	.070	.352	-.010	.883	---	---	---	---	---	---
Capacity general	.121	.211	-.557	.042	---	---	---	---	---	---
Number of axles			-.898	.004	-.349	.004	-.094	.500	---	---
Speed loaded			.029	.689	---	---	---	---	---	---
Speed unloaded			-.069	.443	---	---	---	---	---	---
Tare weight			.784	.000	.655	.000	.584	.000	.502	.000
Axle diameter			-.088	.235	---	---	---	---	---	---
Non-metric										
Bogie family Y25							-.292	.002	-.333	.000
Bogie family other							-.141	.058	-.175	.012
Brake family Oerlikon									-.117	.077
Brake family other									.041	.512
N	98		98		98		98		98	
Adj. R^2	46.7%		60.7%		60.2%		63.3%		64.3%	

Model 8, the last model manually based on theoretical and preliminary statistical findings, explains 73.2% of the variance in freight wagon value. This is the best result compared with previous models and considerable higher than for Model 1. However, several variables are not significant, showing that it is not possible to improve Model 7 in a satisfactory fashion.

Model 9 is the first result of using the Stepwise function. In a similar approach as for locomotives, all metric variables are considered again to check for multicollinearity with any non-metric variables.

The eight-variable model shows a considerable improvement in the percentage of variance explained with a value of 85.5% for the Adjusted R^2. However, as expected, it raises concerns about possible multicollinearity between *Capacity general* and *Number of axles*. Both have a very strong relationship with *Value* and are highly significant. Multicollinearity statistics confirm these concerns with very high VIF-values of 18,615 and 21,652 respectively. Less apparent, but also showing signs of multicollinearity is *Tare weight* with a VIF-value of 4.829.

Correcting for the presence of multicollinearity in Model 9, sees *Number of axles* and *Tare weight* removed in Model 10. The value of the Adjusted R^2 has decreased to 81.2%, but this is still higher than for manually specified models. With six variables, a parsimonious model is established. A strong negative relationship between *Age* and *Value* is witnessed, as well as a positive relation between $Cap_{general}$ and *Value*. The relevance of *Axle diameter*, *No revision*, *Sector break-bulk* and *Sector cars* underlines the important influence of variables other than *Age* on freight wagons value.

Table 28: Freight wagons (linear) - Results - Pt. 2

Model	6		7		8		9		10	
Metric	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**
Age	-.456	.000	-.518	.000	-.458	.000	-.241	.000	-.349	.000
Index freight market	---	---	---	---	---	---	---	---	---	---
Capacity general	---	---	---	---	---	---	.987	.000	.303	.000
Number of axles	---	---	---	---	---	---	-.976	.000	---	---
Speed loaded	---	---	---	---	---	---	---	---	---	---
Speed unloaded	---	---	---	---	---	---	---	---	---	---
Tare weight	.520	.000	.528	.000	.317	.000	.401	.000	---	---
Axle diameter	---	---	---	---	---	---	.201	.000	.282	.000
Non-metric										
Bogie family Y25	-.322	.000	-.247	.004	-.103	.246	---	---	---	---
Bogie family other	-.156	.022	-.127	.063	-.054	.398	---	---	---	---
Brake family Oerlikon	---	---	---	---	---	---	---	---	---	---
Brake family other	---	---	---	---	---	---	.096	.020	---	---
No revision	-.136	.054	-.156	.027	-.150	.020	-.139	.004	-.192	.000
Manufacturer Eastern Europe			-.170	.056	-.034	.694	---	---	---	---
Sector liquid bulk					.770	.443	---	---	---	---
Sector break-bulk					.540	.591	---	---	.119	.009
Sector intermodal					-.150	.881	---	---	---	---
Sector coils/plates					.209	.790	---	---	---	---
Sector cars					.365	.000	.660	.000	.694	.000
N	98		98		98		98		98	
Adj. R^2	64.6%		65.6%		73.2%		85.5%		81.2%	

4.3 Interpretation of the regression variate

Both for locomotives and freight wagons, hand-built models are created. These models are compared to models using the Stepwise procedure, listing only the strongest relations between variables. Based on the results, it is concluded for locomotives that significant variables in early models remain significant in later models. The results from Stepwise models correspond well with outcomes of the final theory-driven models, if non-significant outcomes of the latter are disregarded.

4.3.1 Locomotives

Stepwise Model 10 is the preferred model. With 83%, its R^2-value is highest. Collinearity levels are satisfactory low (Table 29). Three of the broad explanatory factors established in Chapter 2 are included. It concerns: *Sector* (*Sector shunter*), *Age, Features* (*Power rating primary*, *Speed*, *Gauge*, *ETCS L2*). The broad factor *Earnings* is not represented, as the state of the rail freight and passenger rail markets is not relevant. Especially for the passenger rail market this was unexpected, given the strong correlation found earlier.

In addition, it is concluded that the coefficients of the explanatory variables all show the expected signs, as set out in Section 3.5. Only for *Sector shunter*, the result is surprising. One would expect a negative sign of the coefficient, when one considers that these locos standardly have a lower value than mainline locomotives. However, a positive coefficient can be the result of a compensation for the low power rating and speed, which add less value to the constant than for mainline locomotives.

Here, the constant is the base price for a vehicle that has a value of zero for all explanatory variables (€-5,195,619). Per extra unit of explanatory variable, the value of the vehicle increases or decreases by the corresponding value of the unstandardized coefficient, when all other variables remain the same. For example, for every extra km/h of maximum speed, €10,745 is added to the locomotive's base value. Based on the found coefficients, the following regression equation is determined to estimate the *Value* of a locomotive.

$$\begin{aligned} Value\ (€) = & -5{,}195{,}619 + (-32{,}624 * Age) + \left(204 * Power_{primary}\right) + (10{,}475 * Speed) \\ & + (775{,}831 * ETCS_{L2}) + (-638{,}254 * Man_{east}) + (533{,}215 * Sector_{shunt}) \\ & + (4{,}009 * Gauge) + \varepsilon \end{aligned}$$

EQUATION 9: MODEL 10 - LOCOMOTIVES

When looking at the standardized coefficients, the relative influence of the different explanatory factors can be compared. This reveals that:

- age has the largest influence on value, in line with its influence on the book value in practice;
- the primary power output, maximum speed and track gauge all have a considerable positive effect on value;
- on-board ETCS Level 2 has an significant influence, considering its high share in the total vehicle price in practice;
- vehicles built in Eastern Europe are valued lower than those built in Western Europe;
- sectors exist, as other explanatory factors have less influence on shunter value than on mainline locomotive value.

TABLE 29: DETAILED RESULTS (LINEAR) - LOCOMOTIVES

MODEL	**10**						
	Unstandardized coefficients		**Stand. coefficients**			**Collinearity statistics**	
	B (€)	**Std. Error**	**β**	**t**	**Sig.**	**Tolerance**	**VIF**
Constant	-5,195,619	1,899,907		-2.735	.007		
Age (year)	-32,624	2,976	-.495	-10.962	.000	.642	1.558
Power rating primary (kW)	204	42	.296	4.853	.000	.352	2.844
Speed (km/h)	10,745	2,492	.337	4.312	.000	.215	4.657
ETCS L2	775,831	259,918	.112	2.985	.003	.935	1.070
Gauge (mm)	4,009	1,263	.119	3.176	.002	.928	1.078
Manufacturer Eastern Europe	-638,254	136,335	-.175	-4.682	.000	.938	1.066
Sector shunter	533,215	198,221	.154	2.690	.008	.400	2.499

4.3.2 FREIGHT WAGONS

Using the Stepwise function, the outcomes are slightly different from the intuitively set up models (Table 30), but, with 81.2%, its R^2-value is highest. The difference is not problematic, as a switch occurred between two highly correlated variables of which only one is included per model (*Tare weight* vs. *Capacity general*). The collinearity statistics show satisfactory low levels. Overall, the model includes most of the broad explanatory factors, namely: *Sector* (*Sector break-bulk*, *Sector* *cars*), *Age* (*Age*), *Capacity* (*Capacity general*), *Features* (*Axle diameter*), *Other* (*No revision*) are all represented in this model.

The signs of the coefficients of the explanatory variables all match the expectations set out in Section 3.5. Again, the constant is the base price for a vehicle that has a value of zero for all explanatory variables (€-469,013). Per extra unit of explanatory variable, the value of the vehicle increases or decreases by the corresponding value of the unstandardized coefficient, when all other variables remain the same. For instance, every extra year added to a wagon's age, its base value decreases by €908. Based on the found coefficients, the following regression equation is determined to estimate the *Value* of a freight wagon.

$$\begin{aligned} Value\ (€) = {} & -469{,}013 + (-908 * Age) + (729 * Cap_{general}) + (541 * Diameter_{axle}) \\ & + (-21{,}268 * Rev_{no}) + (14{,}824 * Sector_{break}) + (226{,}377 * Sector_{cars}) + \ \varepsilon \end{aligned}$$

EQUATION 10: MODEL 10 – FREIGHT WAGONS

When looking at the standardized coefficients, the relative influence of the different explanatory factors can be compared. This reveals that:

- age has a considerable negative influence on wagon value;
- a higher general cargo capacity in tonnes and the axle diameter positively influence value considerably;
- a wagon not in a valid maintenance regime is valued considerably lower;
- car transporters and break-bulk wagons (e.g. sliding wall wagons) are valued higher than other wagons, so sectors exist.

TABLE 30: DETAILED RESULTS (LINEAR) - FREIGHT WAGONS

MODEL	**10**						
	Unstandardized coefficients		**Stand. coefficients**			**Collinearity statistics**	
	B (€)	**Std. Error**	**β**	**t**	**Sig.**	**Tolerance**	**VIF**
Constant	-469,013	94,903		-4.942	.000		
Age (year)	-908	166	-.349	-5.462	.000	.475	2.107
Capacity general (tonne)	729	144	.303	5.078	.000	.545	1.834
Axle diameter (mm)	541	103	.282	5.247	.000	.672	1.487
No revision	-21,268	5,693	-.192	-3.736	.000	.732	1.367
Sector break-bulk	14,824	5,565	.119	2.664	.009	.976	1.025
Sector cars	226,377	17,815	.694	12.707	.000	.651	1.537

4.4 EVALUATION AND VALIDATION

First, explanatory power is assessed, followed by the generalizability of the results. Subsequently, evaluation of the found relationships takes place by means of visual validation. Then, a number of diagnostic techniques are applied to see how well the assumptions for multiple regression hold, to provide more certain results with respect to the presence of linearity. A detailed evaluation is performed in Appendix A10-A12.

4.4.1 EXPLANATORY POWER

At a sample size of 100 cases and a power of 0.80, the minimum R^2 value that can be found statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. For a sample size of 250 cases, it lies between the 5% and 6%.

Using 128 cases and 7 independent variables, the minimum R^2 values are sufficiently low and explanatory power of the locomotive model is sufficient. Estimated using 98 cases and 6 independent variables, the same applies to the freight wagon model.

4.4.2 GENERALIZABILITY OF RESULTS

A ratio of 15 to 20 cases per explanatory variable is preferred. Increasing the significance level from 0.05 to 0.1, which may be done to find effects becoming statistically significant earlier and thus seeing more variables added, would endanger generalizability of the outcomes.

The final locomotive model has a ratio of 18.3 cases per independent variable, which lies well between the preferred range of 15 to 20. The inclusion of more variables would lower the ratio to 1:16 or less, which is not preferred.

For freight wagons, the ratio is 1:16.3, which only just lies within the preferred range. Also here, a significance level higher than 0.05 or the inclusion of more variables is only preferred when more cases are available.

4.4.3 EVALUATION OF LINEARITY

Where in ship and aircraft valuation the presence of non-linear influences on vehicle value has been established in theory, this is not yet the case for rail vehicle valuation. Therefore, the basic assumption that linearity exists unless proven otherwise, was made beforehand. A closer look at the outcomes by means of visual evaluation hints at non-linear relationships between certain explanatory variables and value. Their possible existence is further analysed in Appendix A10.

For locomotives, visual evaluation reveals a doubtful, but not fully inappropriate, linear influence of *Age* and *Power rating* on value.

Based on a visual evaluation of the results linear wagon value estimation is not fully inappropriate for *Age* and *General cargo capacity*. Similar to the relationship between *Gauge* and *Value* for locomotives, a valid relationship between *Axle diameter* and *Value* cannot be supported, neither linear nor non-linear.

4.4.4 NORMALITY OF THE PREDICTION ERROR, LINEARITY OF THE MODEL AND HOMOSCEDASTICITY

In both models, the assumption of normality of the error terms is met. Further assessment of linearity and homoscedasticity shows that the doubts raised during visual evaluation are in place.

Especially for locomotives, the assumption of linearity is very questionable, indicating that a curvilinear shape of the value function may be more appropriate.

Freight wagon data still leaves some room for the presence of non-linearity between the explanatory factors and wagon value. The linearity check supports the visual evaluation, concluding that linear value estimation is more appropriate for vehicle type.

4.4.5 SIGNIFICANCE OF REGRESSION COEFFICIENTS

Based on an evaluation of the standard errors and a visual assessment of the confidence intervals, **Fout! Verwijzingsbron niet gevonden.** gives an overview of the expected variation in the value of the coefficients due to sampling error. Variation is relatively less for the coefficients in the freight wagon model than for the locomotive model. Overall, high variation is mainly found for the coefficients of non-metric variables.

For all coefficients, statistical significance was established (i.e. the confidence interval does not include zero) and visually confirmed. However, visual evaluation reveals that for *ETCS L2*, *Sector shunter* and *Sector break-bulk*, the confidence bands leave room for a coefficient of almost zero.

Table 31: Uncertainty regression coefficients

Variable	β	B	Std. error	Lower bound	Upper bound	Interval	Exp. variation coef. value	
Locomotives							**t**	**Rank**
Constant		-5,195,619	1,899,907	-8,957,302	-1,433,935	7,523,367	-2.735	High
Age (year)	-.495	-32,624	2,976	-38,516	-26,731	11,785	-10.962	Low
Power rating primary (kW)	.296	204	42	121	288	167	4.853	Med.
Speed (km/h)	.337	10,745	2,492	5,811	15,679	9,868	4.312	Med.
ETCS L2	.112	775,831	259,918	261,212	1,290,449	1,029,237	2.985	High
Gauge (mm)	.119	4,009	1,263	1510	6,509	4,999	3.176	High
Manufacturer Eastern Europe	-.175	-638,254	136,335	-908,188	-368,319	539,869	-4.682	Med.
Sector shunter	.154	533,215	198,221	140,751	925,680	784,929	2.690	High
Freight wagons								
Constant		-469,013	94,903	-657,527	-280,499	377,028	-4.942	Med.
Age (year)	-.349	-908	166	-1,238	-578	660	-5.462	Med.
Capacity general (tonne)	.303	729	144	444	1,014	570	5.078	Med.
Axle diameter (mm)	.282	541	103	336	746	409	5.247	Med.
No revision	-.192	-21,268	5,693	-32,577	-9,959	22,617	-3.736	Med.
Sector break-bulk	.119	14,824	5,565	3,770	25,879	22,110	2.664	High
Sector cars	.694	226,377	17,815	190,990	261,765	70,776	12.707	Low

4.5 Conclusions

In this chapter, linear value functions are established for locomotives and freight wagons. It reveals that it is possible to create parsimonious models for both vehicle types that are able to explain the majority of variance in vehicle value. At the same time, they cover the five broad explanatory variables, as well as rail-specific variables. However, post-hoc evaluation and validation of the results does not take away the doubt regarding the possible existence of non-linear relationships between the independent variables and vehicle value. Therefore, the inclusion of non-linear variables is researched in Chapter 5.

5: Non-linear model specification, evaluation and validation

> *"It's essential to focus on creating value and not just harvesting huge amounts of data, because data alone is only cost. The real benefit comes when you can turn it into insights."*
>
> *Gerhard Kress, Director Mobility Data Services, Siemens Mobility*
>
> (Barrow, 2018)

Visual evaluation of the results in Chapter 4 reveals relationships between explanatory factors and vehicle value, of which linearity is doubtful. This chapter covers the inclusion of quadratic explanatory factors to research if non-linear influences on value exist and evaluates the outcomes.

5.1 Working towards a non-linear model: locomotives

To find any non-linear influences on locomotive value, additional variables are created from the original metric explanatory variables.

5.1.1 Model specification

These additional variables are transformed from the original ones by raising them to the second power. The original and newly created quadratic explanatory variables are then selected for entry into the model. Similar to the linear model, corrections are made manually in case of multicollinearity between explanatory factors.

The following quadratic variables are created and used as input with their metric counterparts:

Age^2, *Index passenger market*^{2}, *Index freight market*^{2}, *Gauge*^{2}, *Number of axles*^{2}, *Power rating primary*^{2}, *Number of voltage systems*^{2}, *Number of country approvals*^{2} and *Speed*^{2}.

5.1.2 Results and interpretation

Using the Stepwise selection procedure of SPSS, a non-linear model is found. With an Adjusted R^2 of 88.9%, it is able to explain a larger part of the variance in *Value* than the linear model (83.3%).

Results

The results are listed in Table 32. All coefficient signs are as expected. High multicollinearity is found between the metric variables and their quadratic counterparts, as expected. Note: *Age* vs. *Age*^{2} and *Power rating primary* vs. *Power rating primary*^{2}. Some coefficients have been rounded for ease of reading. The reader is referred to Appendix A13-A14 for the detailed results.

Table 32: Locomotives (non-linear) - Results

Locomotives (Adj. R^2 = 88.9%)							
	Unstandardized coefficients		**Stand. coefficients**			**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Tolerance**	**VIF**
Constant	523,117	193,930		2.697	.008		
Age	-86,385	7927	-1.312	-10.897	.000	.060	16.561
Age^2	1,042	148	.876	7.042	.000	.057	17.661
Power rating primary	1,128	131	1.637	8.626	.000	.024	41.157
Power rating primary^2	-.123	.018	-1.206	-7.023	.000	.030	33.694
Number of country approvals^2	32,890	7340	.161	4.481	.000	.674	1.483
Speed^2	18	7	.135	2.594	.011	.321	3.111
Manufacturer Eastern Europe	-508,111	113,019	-.139	-4.496	.000	.911	1.098
Sector shunter	591,311	165,405	.171	3.575	.001	.384	2.606

Evaluation and validation

At a sample size of 100 cases and a power of 0.80, the minimum R^2 value that can be found statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. For a sample size of 250 cases, it lies between the 5% and 6%. Using 128 cases, the minimum R^2 values are sufficiently low and explanatory power is sufficient.

Generalizability of the outcomes is maintained, albeit a bit lower than for the linear model. With 128 cases and eight variables, the ratio is 16 cases per independent variable. This is still within the preferred range of 15 to 20.

For a visual evaluation of all the partial regression plots, the readers is referred to Appendix A13. To summarize most important findings:

- Doubt regarding the linearity of the relationship between *Age* and *Value* was appropriate. *Age* and *Age*^{2} both acknowledge the existence of non-linearity.
- The same applies for *Power rating primary*: the non-linear model better describes the relationship with *Value* through the inclusion of *Power rating primary* and *Power rating primary*^{2}.

Any outliers in visible in the partial plots are valid cases. Excluding them from the analysis does not result in substantially different outcomes for coefficient or the R^2 values.

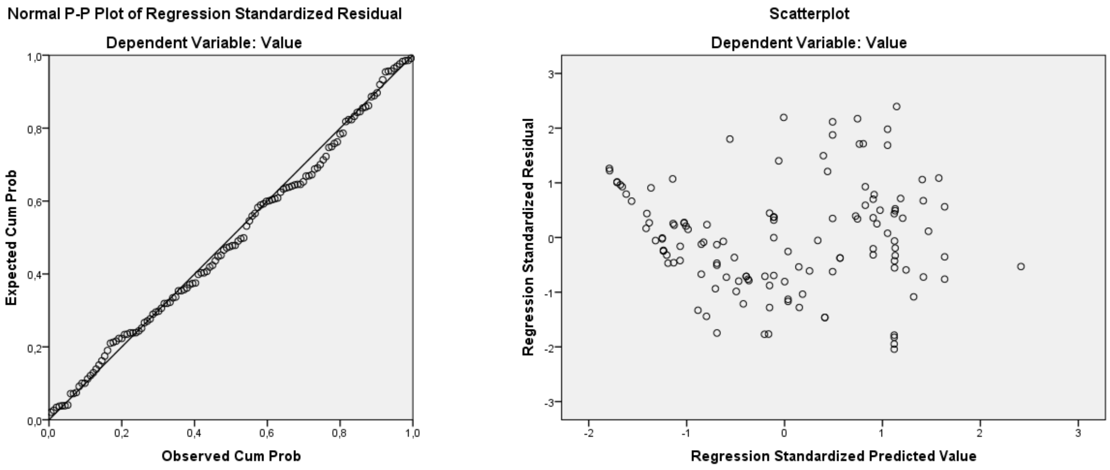

Figure 11: Locomotives (non-linear) - Normal Probability Plot (l) & Standardized Residuals (r)

The normal probability plot of the standardized residual for the locomotive model is visualized in Figure 11. The values are nicely in line with the diagonal, the assumption of normality for the prediction error term is met.

The scatterplot in Figure 11 shows the standardized residual plotted against the standardized predictive value. There is no clear pattern of increasing or decreasing residuals, which indicates homoscedasticity. Naturally, linearity is not appropriate and the original doubt when assessing the linear model is in place.

5.2 Working towards a non-linear model: freight wagons

For freight wagons, the same process is followed as for locomotives to identify possible non-linear relationships.

5.2.1 Model specification

The following quadratic variables are created prior to analysis:

Age^2, *Index freight market*^{2}, *Number of axles*^{2}, *Speed loaded*^{2}, *Speed unloaded*^{2}, *Tare weight*^{2}, *Capacity general*^{2}and *Axle diameter*^{2}.

Of the variables listed above, multicollinearity occurs between two sets of variables. The first set comprises of *Number of axles*, *Tare weight* and *Capacity general*. This set is simplified by using only *Capacity general*. The second set comprises of *Speed loaded* and *Speed unloaded*. Of these two variables, *Speed loaded* is further used for analysis.

5.2.2 Results and interpretation

The Stepwise selection procedure is used to form a model. A non-linear model is found, which includes the variables *Age*, *Age*^{2}, *Capacity general*^{2}, *No revision*, *Sector cars* and *Sector intermodal.* However, *Capacity general*^{2} returns an unstandardized coefficient of almost zero and a standard error, as well as confidence bounds of zero. The choice is made to exclude *Capacity general*^{2} and the selection procedure is run again. The result is a more logical model featuring the same variables, but with *Capacity general* instead of *Capacity general*^{2}. With an Adjusted R^2 value of 78.4%, the model explains slightly less variance than the linear model (81.2%).

Results

Table 33 lists the results for the final non-linear freight wagon model. All coefficient signs are as expected. Also here, high multicollinearity is limited to the original metric variables and their quadratic counterparts. Note *Age* vs. *Age*^{2}. Again, some coefficients have been rounded for ease of reading and Appendix A13-A14 present the detailed results.

Table 33: Freight wagons (non-linear) - Results

Freight wagons (Adj. R^2 = 78.4%)							
	Unstandardized coefficients		**Stand. coefficients**			**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Tolerance**	**VIF**
Constant	32,017	11,623		2.755	.007		
Age	-2,381	447	-.916	-5.324	.000	.075	13.311
Age^2	36	9.596	.603	3.704	.000	.084	11.891
Capacity general	.792	.161	.329	4.911	.000	.496	2.018
No revision	-16,361	6033	-.148	-2.712	.008	.747	1.339
Sector cars	168,785	16,153	.518	10.449	.000	.907	1.102
Sector intermodal	-12,425	5.837	-1.07	-2.128	.036	.888	1.126

Evaluation and validation

To estimate the freight wagon model, 98 cases are used. The result is an Adjusted R^2 of 78.4%. For 100 cases and a power of 0.80, the minimum R^2 value that can be found statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. Also here, the minimum R^2 values are sufficiently low, so the explanatory power is sufficient.

Generalizability of the outcomes is maintained here too. With 98 cases and 6 variables, the ratio remains at 18.3 cases per independent variable. This is within the preferred range of 15 to 20.

A full visual evaluation of the partial regression plots is performed in Appendix A13. To summarize most important findings:

- Doubt regarding the linearity of the relationship between *Age* and *Value* is appropriate for freight wagons too. *Age* and *Age*^{2} both acknowledge the existence of non-linearity.
- Doubt regarding the linearity of *Axle diameter* is taken away, as it is no longer included.
- Corrected for the presence of other variables, *Capacity general* shows a clear linear relationship with *Value*.

Normality of the error term of the variate holds, despite a more s-shaped curve of the plot (Figure 12). No strong departures from the diagonal are observed.

Additionally, the scatterplot shows no clear pattern of increasing or decreasing residuals, which indicates homoscedasticity. Naturally, linearity is not appropriate and the original doubt when assessing the linear model is in place.

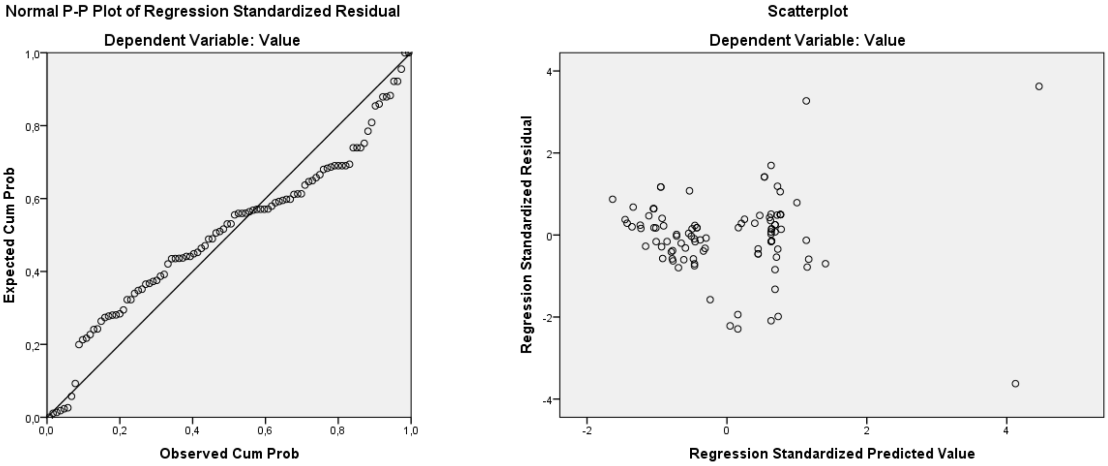

Figure 12: Freight wagons (non-linear) - Normal Probability Plot (l) & Standardized Residuals (r)

5.3 Conclusions

This chapter is dedicated to the identification of possible non-linearity in the relationships between the explanatory factors of locomotive and freight wagon value. It shows that non-linearity exists for both vehicle types.

5.3.1 Locomotives

The locomotive model acknowledges the presence of non-linearity between several explanatory factors and value. This is discovered through the inclusion of *Age*, *Age*^{2}, *Power rating primary*, *Power rating primary*^{2}, *Number of country approvals*^{2}, *Speed*^{2}, *Dummy manufacturer Eastern Europe*, *Dummy sector shunter*. It takes away the initial doubt with respect to the linearity of the relationships between *Age* and *Value*, as well as *Power rating primary* and Value. With an Adjusted R^2 of 88.9%, the non-linear model is able to explain a larger part of the variance in *Value*, than the final linear model (83.3%).

5.3.2 Freight wagons

The freight wagon model does not show an increase in Adjusted R^2 value. In fact, it is 2.8% lower with a value of 78.4% compared to 81.2% of the linear model. However, the discovery of non-linear relationships makes it the preferred model over the linear one. It concerns the inclusion of *Age*, *Age*^{2}, *Capacity general*, *No revision*, *Sector cars* and *Sector intermodal.* The inclusion of *Age*^{2} proves the existence of non-linearity, but also causes the effect of a different variable to be excluded. Thereby, it lowers the level of explained variance slightly compared to the linear model.

6: SUMMARY AND CONCLUDING REMARKS

"With data from rail assets, it is possible to improve the value for the asset owner…"

Gerhard Kreß, Siemens Germany

(ProMedia Europoint BV | RailTech.com, 2016a)

Section 6.1 provides qualitative and quantitative answers to the research questions of this thesis, followed by concluding remarks with respect to the outcomes in Section 6.2. Section 6.3 discusses the limitations of this research, followed by recommendations for future research in Section 6.4.

6.1 SUMMARY OF RESULTS

Seven research questions form the basis of this thesis, which are answered one by one. Combined, this provides an answer to the main, two-fold, research question.

1. *What are the main determinants of locomotive and freight wagon value; and*
2. *how does locomotive and freight wagon value depend on these factors economically and statistically?*

6.1.1 DATA AVAILABILITY AND RELEVANCE OF RESULTS

I. *How frequent are sale and purchase transactions for rail rolling stock? Is the size of the market sufficiently large and does it provide sufficiently available data of a satisfactory quality for a reliable application of more automated valuation techniques?*

The number of sales and purchases, and the amount of publicly available data, determine to what extent valid quantitative analysis can be performed. Moreover, the amount of data available has a direct influence on how broad the scope can be with respect to vehicle types.

With total yearly investments in new vehicles exceeding eight billion euros, the rail vehicle market is of great economic importance. Table 34 lists the yearly quantities of traded rail vehicles, excluding urban rail and specialized engineering vehicles. The yearly number of freight wagons traded on the second-hand market is unknown. Based on the ratios between new and second-hand for other vehicle types, this may amount between 10% and 20% of the number of new wagons. Assuming full insight in all transactions, the market size is sufficient for the estimation of valuation models.

TABLE 34: MARKET SIZE NEW AND USED RAIL VEHICLES

VEHICLE TYPE	NEW	SECOND-HAND
Multiple units and rail cars	900	80
High speed trains	50	-
Passenger coaches	400	80
Locomotives	800	300
Freight wagons	10,000	- (unknown)
Source: Metz & Radstake (2013)		

Despite its large size, the rail vehicle market is less transparent than the aircraft and ship markets. Only for locomotives and freight wagons sufficient data was available (128 and 98 transactions respectively), setting the scope of the thesis to these vehicle types. Although seemingly small numbers compared to the size of the market, these values lie between general guidelines of minimally 30 and maximally 1,000 observations for sufficient statistical power.

The available data enables the estimation of parsimonious models, keeping a preferred ratio between 1:15 and 1:20 in mind between the number of explanatory variables and the number of available cases. This ensures that generalizability of the results is maintained. The disadvantage of this is that a restrictive significance level (α) of 0.05 is used and only the strongest effects of explanatory effects on value can be taken into account. Even though the direction (+/-) of the effects on value are known and a less restrictive α of 0.10 could be used, the amount of independent variables that can be included in the models is limited to safeguard generalizability and prevent overfitting. This may mean that some effects which exist in reality are now not included in the model.

However, the available data is balanced and of high quality. It benefits from objectively measured variables and the high standardization in the rail sector, decreasing the number of systematic differences between sample and population. Furthermore, special vehicles with extraordinary parameter values are excluded (e.g. hybrids, engineering vehicles). Overall, both samples are sufficiently representative for the total locomotive and freight wagon populations.

6.1.2 THE EXISTENCE OF SECTORS

II. Do 'Sectors' exist in rail? If so, how should they be defined?

The answer to this question is two-folded. The answer to the first part of this question is simple: yes. Analogue to ship and aircraft valuation, it is possible to determine sectors for rail vehicles and to provide quantitative support for this.

LOCOMOTIVES

Locomotive sectors are theoretically differentiated by function (i.e. mainline vs shunting) and propulsion (i.e. diesel vs electric). Quantitative analysis supports the existence of sectors with a structural value difference between mainline and shunting locomotives. Base shunter values are corrected with a positive sum. One would expect a negative coefficient, considering that they standardly have a lower value than mainline locomotives. The positive sum compensates for lower power rating and speed, which add less value. Furthermore, it is seen as a sign of added value stability over time thanks to flexibility in use. A differentiation between electric and diesel cannot be supported, even though theory proposes a difference based on the vehicles' economics.

FREIGHT WAGONS

Traditionally, freight wagons are categorized using the letter-based UIC classification system. Overlap in classes prevents its use (e.g. intermodal and coil wagons can both be type 'S'). Six new categories are defined according to cargo appearance, analogue to shipping, such that they have similar economics with respect to technical and market aspects (Table 35).

TABLE 35: SECTORS - FREIGHT WAGONS

SECTOR	REMARKS	UIC WAGON CLASSES
Dry bulk	Ores, grains, fertilizers, etc.	E, F, T
Liquid bulk	Liquids, gases, slurries, powders, etc.	U, Z
Intermodal	Containers, swap bodies, trailers, etc.	K, L, R, S
Break-bulk	Pallets, boxes, fresh food, timber, pipes, etc.	G, H, I, K, O, R
Cars	Cars, vans, etc.	H, L
Coils/Plates	Metal coils and plates of different sorts, such as steel, aluminium, etc.	S

Quantitatively, the existence of sectors is supported. Car transporter values are structurally higher than other wagon values - this coefficient is also surrounded with the highest uncertainty due to the relatively small number of cases - intermodal wagon values are corrected with a negative sum.

6.1.3 THE INFLUENCE OF AGE ON VALUE

III. How does the ´Age' of rail vehicles influence their market value?

Common industry practice is taking vehicle book value as a starting point to determine a suitable selling price, which is corrected for technical features and vehicle condition. The final Fair Market

Value includes a deviation factor too, representing the effects of supply and demand. By the use of book value, age has an important share in the market value of rail vehicles.

Quantitative analysis of the influence of age on vehicle value supports its relevance. It proves to be the most relevant determinant. Although the effect of age on book value is linear in practice, general asset valuation theory proposes negative curvilinear alternatives to account for:

- the decreasing usefulness of high-tech assets over time; and
- the decreasing benefits due to increased operating costs over time.

Analysis shows that a curvilinear modelled influence of vehicle age on market value is preferred over a linear one. Hereby, the relationship follows a strongly decreasing line at first, which then slowly stabilizes at higher ages to a base value.

6.1.4 The relation between capacity and value

IV. *How should the factor 'Capacity' be defined in rail valuation? And if defined, how does it influence the market value of rolling stock?*

Locomotives

For locomotives, an indirect notion of capacity is impossible for two reasons:

- The vehicle itself does not offer any direct capacity for freight or passengers.
- Alternative indicators, such as starting tractive effort, are problematic. Heavy trains may exist of empty wagons with a high tare weight and relatively low capacity or vice versa.

Freight wagons

For freight wagons, there are two ways to define capacity:

- The maximum capacity in tonnes at the highest permissible axle load, referred to as the general cargo capacity.
- Sector-specific indicators, as can be seen in Table 36.

Table 36: Capacity indicators - Freight wagons

Vehicle sector	**General capacity indicator**	**Sector-specific capacity indicator**
Locomotive	n/a	n/a
Freight wagon		
- Dry Bulk	Tonnes	Cubic metres
- Liquid Bulk		
- Intermodal		Feet
- Break-bulk		Usable loading area
- Cars		Tonnes
- Coils/plates		Tonnes

In the quantitative part of this research, the general cargo capacity represents the broad explanatory factor *Capacity*. Due to data availability, the compromise is made to disregard sector-specific capacity indicators and opt for the general indicator.

The multiple regression models underpin the influence of freight wagon capacity on market value. Corrected for other variables in both the linear and non-linear model, the relationship between cargo capacity and wagon value follows a positive and linear shape. This matches the principle that a wagon's earning potential increases through higher capacities. The result is a better position in the market and thus a higher market value.

6.1.5 AN ALTERNATIVE FOR EARNINGS IN RAIL VEHICLE VALUATION

V. Is there a notion of 'Earnings' that is relevant to rolling stock values? If so, what? And, how is it of influence on the market value of rail vehicles?

Using similar notions of earnings as ship or aircraft valuation is difficult due to non-transparency in the rail market and inherent differences between the markets. Rail freight services are mainly contract-based – with the exception of wagonload transport – so the rate per unit of cargo cannot be straightforwardly determined. Earnings are also not easily determined for every vehicle type. Geographically varying ticket fees and subsidies make earnings difficult to define for passenger vehicles. Moreover, the earnings of locomotive-hauled trains are assigned to the wagons.

Therefore, an alternative notion of earnings, suitable to include in models and representing market influence, is sought. Three alternatives are considered.

1. **Operating lease rates**
   Using operating lease rates as market indicator is problematic, because they:
   - suffer from non-transparency, making it an unpractical variable.
   - are relatively static over time, as they are linked to the purchase price of a vehicle and fluctuating rates may endanger the return on investment for the lessor.
2. **Manufacturer book size/earnings and/or the number of scrapped vehicles**
   The inclusion of manufacturer order book size, manufacturer earnings and/or the number of scrapped vehicles per year is inter alia found in theoretic ship valuation models to model the demand for ships. However, it is unpractical for rail for reasons of non-transparency.
3. **Performance of the rail transport market**
   The most practical alternative is the performance of the rail transport market under the assumption that increased demand for rail transport translates to increased demand for rail vehicles. This thesis uses two separate indicators: the yearly number of performed tonne-kilometres for rail freight and the yearly number of passenger-kilometres for passenger rail.

Quantitatively, no significant influence of the market state on locomotive nor freight wagon value is observed for the thirteen-year period from 2004 to 2016, supporting reasons mentioned in theory:

- The market for passenger vehicles performed well during the economic crisis of 2008. Vehicle acquisitions were hardly affected, thanks to new passenger franchises.
- Even during the economic crisis, sufficient funds were available for investments.
- The link with market performance has become less, as there is a trend towards using multiple units instead of locomotives for passenger operations.
- Used freight wagons find a new home quickly. When demand is strong and stable in this relatively small second-hand market, stable prices are the result.

6.1.6 THE INFLUENCE OF TECHNICAL FEATURES ON VEHICLE VALUE

VI. What 'Features' (i.e. technical specifications and equipment) of rail vehicles are relevant determinants of market value and how do they influence it?

The influence of technical features on value is widely acknowledged in ship, aircraft and general asset valuation theory. General asset valuation emphasizes the importance of technical features through the concept of physical-asset specificity. It indicates that the more technically standardized a vehicle is, the more resale potential it has and the higher its intrinsic market value. Theory and practice in aircraft and ship valuation underline the importance of these features too, for multiple reasons:

- Technical features include factors related to a vehicle's efficiency (e.g. speed and fuel consumption) and influence its ability to generate earnings under varying market conditions.
- Certain technical features, such as compliance with specific standards, offer operational flexibility and influence resale potential. Both aspects have an intrinsic value.
- Technical features have a specific value and partly determine how well it can compete with other and/or newer vehicles with similar specifications.

Also, the relevance of compliance with certain standards is emphasized, including noise and exhaust emission legislation, but also how modern a vehicle is relative to current regulations. Lastly, the value of flexibility is important with a focus on country approvals, because certification of vehicles – especially used ones – in other countries is very costly relative to their value.

LOCOMOTIVES

Quantitatively, the main technical features found to be of influence on locomotive market value are:

3. **Primary power rating**
   The higher a locomotive's power rating, the higher its market value. Analysis shows it influences market value in a curvilinear way, adding value rapidly at first but less and less when power ratings increase to the highest regions due to the inclusion of a negative quadratic variable.
4. **Maximum speed**
   The maximum speed of a locomotive also influences its value in a non-linear fashion. Speed is included as a quadratic variable, adding value per every unit of speed slowly at first and increasingly fast for higher maximum speeds.

FREIGHT WAGONS

For freight wagons, no specific technical features are found to be of influence on market value. Of an extensive set of input variables (i.e. track gauge, number of axles, maximum speed when loaded, maximum speed when unloaded, tare weight, bogie type, axle diameter and brake type) only tare weight is partly represented through its high multicollinearity with the general wagon capacity. Market value is mainly improved by other factors, predominantly age and capacity.

6.1.7 OTHER DETERMINANTS

VII. Are there any other determinants of value (specific to the rail market)? And, in what way do those determinants influence value?

Other possible determinants of rail vehicle value include:

4. **The location of the manufacturer**
   Ship valuation theory underpins differences between manufacturers from different countries. Due to data limitations, this thesis considers two groups: Western and Eastern European manufacturers. Analysis reveals that locomotives made by Eastern European manufactures are structurally valued lower. In the final locomotive model, they are penalized with an approximate €500,000 decrease in value. The variable is not found to be of influence on freight wagon value.
5. **The number of country approvals**
   About the number of country approvals, asset theory and rail valuation practice consider operational flexibility to increase resale potential and thus market value. In rail valuation, it is important due to the costly certification of second-hand vehicles in other countries.

The number of country approvals is not analysed for freight wagons as all wagons in the dataset have Europe-wide RIV / TEN approval. For locomotives, a quadratic increase in market value is found for every additional country authorization, ceteris paribus.

6. **If a vehicle is in a valid maintenance regime.**
   Practice shows that when a main overhaul or additional maintenance is required, vehicles are valued lower due to the high extra costs involved for the potential buyer. Analytically, the data does not support its influence on locomotive value. In the freight wagon valuation model, wagon value is decreased by circa €16,000 when not in a valid regime.

6.1.8 Final valuation models

This section lists the final valuation models (Table 37 and Table 38) and the influence of the respective valid explanatory factors on the Fair Market Value of locomotives and freight wagons respectively.

Locomotives

The locomotive valuation model can explain 88.9% of the variance in value; the remaining 10.1% is attributed to the state of the vehicle, of which the determination includes some extent of subjectivity, and any potential (external) determinants that could not be included. These are included in the error term (ε).

Table 37: Locomotive valuation model

Locomotives (Adj. R^2 = 88.9%)									
	Unstandardized coefficients		**Stand. coefficients**			**95% Confidence interval for B**		**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Lower bound**	**Upper bound**	**Tolerance**	**VIF**
Constant	523,117	193,930		2.697	.008	139,116	907,117		
Age	-86,385	7,927	-1.312	-10.897	.000	-102,082	-70,689	.060	16.561
Age^2	1,042	148	.876	7.042	.000	749	1,334	.057	17.661
Power rating primary	1,128	131	1.637	8.626	.000	869	1,387	.024	41.157
Power rating $primary^2$	-.123	.018	-1.206	-7.023	.000	-.158	-.089	.030	33.694
$Speed^2$	18	6.9	.135	2.594	.011	4	32	.321	3.111
Number of country $approvals^2$	32,890	7.340	.161	4.481	0.00	18,356	47,423	.674	1.483
Manufacturer Eastern Europe	-508,111	113,019	-.139	-4.496	.000	-731,900	-284,322	.911	1.098
Sector shunter	591,311	165,405	.171	3.575	.001	263,793	918,830	.384	2.606

The constant (€523,117) is the base price for a vehicle with all explanatory variables set to zero. Per extra unit of explanatory variable, ceteri paribus, vehicle value increases or decreases by the corresponding value of the unstandardized coefficient. To illustrate: if a vehicle turns one year old and everything else remains constant, vehicle value decreases by €-86,385 (*Age*), but, in turn, increases by €1,042 (*Age^2*). The following regression equation is the result.

$$\begin{aligned} Value\ (€) = {} & -523{,}117 + (-86{,}385 * Age) + (-1{,}042 * Age^2) + \left(1{,}128 * Power_{primary}\right) \\ & + \left(-.123 * {Power_{primary}}^2\right) + (18 * Speed^2) + \left(32{,}890 * {No_{country\ approvals}}^2\right) \\ & + (-508{,}111 * Man_{east}) + (591{,}311 * Sector_{shunt}) + \ \varepsilon \end{aligned}$$

Equation 11: Regression equation - Locomotives

Freight wagons

The freight wagon model is able to explain 78.4% of the variance in vehicle value; the remaining 21.6% is attributed to the state of the vehicle, of which the determination includes some extent of subjectivity, and any potential (external) determinants that could not be included. These are included in the error term (ε). The originally considered linear model is able to explain slightly more variance in freight wagon value (81.2%), but visual evaluation of the effect of *Age* on *Value* promotes a non-linear relationship. Therefore, the exclusion of a unique variable was accepted in favour of Age^2.

Table 38: Freight wagon valuation model

Freight wagons (Adj. R^2 = 78.4%)									
	Unstandardized coefficients		**Stand. coefficients**			**95% Confidence interval for B**		**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Lower Bound**	**Upper Bound**	**Tolerance**	**VIF**
Constant	32,017	11,623		2.755	.007	8,930	55,104		
Age	-2,381	447	-.916	-5.324	.000	-3,269	-1,492	.075	13.311
Age^2	36	9.596	.603	3.704	.000	16	55	.084	11.891
Capacity general	.792	.161	.329	4.911	.000	.471	1.112	.496	2.018
No revision	-16,361	6033	-.148	-2.712	.008	-28,345	-4,378	.747	1.339
Sector cars	168,785	16,153	.518	10.449	.000	136,700	200,871	.907	1.102
Sector intermodal	-12,425	5.837	-1.07	-2.128	.036	-24,020	-829	.888	1.126

The constant is the base price for a vehicle that has a value of zero for all explanatory variables (€32,017). Per extra unit of explanatory variable, ceteri paribus, vehicle value increases or decreases by the corresponding value of the unstandardized coefficient. To illustrate: if a wagon turns one year old and everything else remains constant, wagon value decreases by €-2,381 (*Age*), but, in turn, increases by €36 (*Age^2*). The following regression equation is the result.

$$Value\ (€) = 32{,}017 + (-2{,}381 * Age) + (36 * Age^2) + \left(.729 * Cap_{general}\right) + (-16{,}361 * Rev_{no}) + (168{,}785 * Sector_{cars}) + (-12{,}425 * Sector_{intermodal}) + \varepsilon$$

Equation 12: Regression equation - Freight wagons

6.2 Concluding remarks

In the introduction of this thesis, the following twofold main research question is defined:

1. *What are the main determinants of locomotive and freight wagon value; and*
2. *how does locomotive and freight wagon value depend on these factors economically and statistically?*

This thesis provides a theoretical basis for rail valuation by means of literature review and taking lessons from practice. Firstly, it describes why it is essential to include the five broad explanatory factors *Sector*, *Age*, *Capacity*, *Earnings* and *Technical features*. Secondly, it is able to provide alternative notions of these broad factors and operationalizes these factors into more detailed variables useable as input for quantitative analysis. As such, this thesis identifies the main determinants of locomotive and freight wagon value in a qualitative way.

Despite some limitations due to the amount of transaction data available, which limits the number of explanatory variables in the model and thus the level of detail, several main determinants of vehicle value have been identified quantitatively. For both locomotives and freight wagons, several main determinants found in literature can be supported quantitatively (also see Section 7.1.8). However, it fails to identify a suitable and quantitatively supported notion of earnings, as no relationship between the state of the passenger rail transport and rail freight markets with vehicle value is found. Nonetheless, the relevance of the majority of the broad factors identified, is underpinned by the results of the statistical data analysis.

Furthermore, insight is given in the nature of the relationships between the respective explanatory variables and rail vehicle value and in the nature of the value function itself through an assessment of the underlying assumptions of multiple regression. Also, the suitability of multiple regression as a technique for the estimation of vehicle value is addressed this way. It is found that the inclusion of non-linear variables is preferred over the use straightforward multiple linear regression, as both the final locomotive and freight wagon reveal the existence of non-linear relationships effects.

Even though straightforward multiple regression is not the most appropriate method when not adapted to include non-linear relationships, the advantage of using a semi-parametric approach becomes clear from the ability to consider multiple non-metric variables. To illustrate this, several non-parametric variables have been found to have a relevant influence on vehicle value, including the manufacturer region and whether a vehicle was in a valid maintenance regime or not. As such, it has been possible to show the statistical dependence of locomotive and freight wagon value on different kinds of explanatory factors.

6.3 RESEARCH LIMITATIONS

This research starts with a qualitative aspect, namely the exploration of literature and considering practical knowledge to provide a theoretical basis. Not only does it look into existing principles in the field of rail vehicle valuation, it also takes a closer look at the possible analogies with asset valuation in general, ship and aircraft valuation. One important finding lies at the basis of using multiple regression, namely its ability to include both quantitative and qualitative. In their review of ship valuation methods, Pruyn et al. (2011) highlighted this advantage over other methods. Additionally, they mention that it is possible to achieve reliable outcomes, even when datasets are moderate in size. In the rail vehicle market, in which publicly available transaction data is relatively sparse compared to ship and aircraft markets, this is a large advantage.

Although linear estimation of value, e.g. with respect to the effect of age on value, seems an acceptable starting point, transformations prove to be required. For reasons of scope, this research limits itself to quadratic transformations to find the most apparent non-linear relationships. This choice is supported by theoretic descriptions regarding the shape of the individual relationships and the ex-ante visualization of inter-variable relationships using scatterplots. However, this does not exclude other types of relationships between variables that have not been researched.

A larger dataset will aid in the inclusion of more variables, as the size of the current dataset provides limitations to the number of variables that can be estimated. Adding a large number of variables to a moderately sized dataset is problematic for the validity of the results, as the risk of overfitting increases. There is a strive for parsimony during the estimation of models in this thesis, as the choice is made that valid results are more important than a model with many detailed variables. This choice has also resulted in a restrictive significance level (α) of 0.05, even though the direction of many effects was known beforehand and an α of 0.10 could have been justified. Possibly, this now leads to the exclusion of variables that may have an effect on vehicle value in real life.

Furthermore, the variables this thesis addresses in the quantitative phase do not cover technical variables related to operational aspects. It is established theoretically that market value also depends on a vehicle’s ability to generate earnings for the owner, as it would not be acquired otherwise. Where this research uses an alternative for the broad explanatory factor *Earnings* by including the state of the respective rail freight and passenger rail markets, it is limited in using indicators for earnings for two reasons. Firstly, it is not possible to assign earnings to every vehicle directly (e.g. locomotives). Secondly, information about operational revenues and costs are non-transparent.

Even though the research takes the broad factor *Earnings* into account through establishing indicators of the state of the passenger rail and rail freight markets, these indicators are not included in the final models as no significant relationships where found. This creates another limitation of the research in the area of economics. Economic theory, and especially the definition of fair market value, are based on the interaction of supply and demand. In the final locomotive and freight wagon models, no demand related variables are present.

Lastly, there is a limitation caused by technical progress. Rolling stock is becoming increasingly modular and upgradable. Power rating or speed may easily be altered and are no longer considered fixed attributes of a vehicle during its lifetime. As a result, this may change the market value attributed to a single megawatt of power or kilometre per hour of speed.

6.4 FUTURE RESEARCH

Future researchers may opt for a different quantitative technique to cope with non-linearity. A main requirement in the eyes of the writer, similar to what Pruyn et al. (2011) concluded in their review of ship valuation methods, is that the technique should be able to include non-parametric variables. Moreover, it should be capable to cover the five broad explanatory factors that play a central role in this research and in aircraft and ship valuation: *Sectors*, *Age*, *Capacity*, *Earnings / State of the market* and *Technical features*, including position in the maintenance cycle.

These requirements exclude the use of parametric techniques other than using them in a confirmatory way to underpin the relevance of the found parametric variables. Proposed is an expansion of this research by using general additive models to include non-linear effects between value and its explanatory variables. These models have the advantage that they can describe the dependence of locomotive and freight wagon value on its explanatory factors using similar additive models as multiple regression, but with the inclusion of smoothed predictor variables or predictor variables that are in turn dependent on other predictor variables.

A second method is proposed in the form of a net present value technique, similar to Vasigh & Erfani (2004), to underpin the relevance of the most important explanatory variables. This as far as they can be monetized, using a completely different technique. The benefit of such a research is that it can be performed according to the established broad explanatory factors S*ectors*, *Age*, *Capacity*, *Earnings / State of the market* and *Technical features*. After establishing the value profiles through the years of the different rolling stock sectors, the outcomes should be compared across these sectors to check which sectors may possibly be grouped together based on similar profiles and which not. A net present value technique would be able to include activity related variables, such as increasing operational costs. However, such a technique has a larger dependency on detailed vehicle data than multiple regression or general additive models. Despite its greater data dependency, a net present value approach is able to identify the extent to which market values of rail vehicles depend on their ability to generate earnings. Such a research should therefore only be undertaken if access to sufficient detailed financial data is available.

High data availability may also open doors for data mining of transaction records, which could be promising for internal research within railway finance organisations/brokers with large rolling stock transaction databases. It requires sufficiently sized datasets to be able to identify patterns. As for multivariate analysis, data quality is of great importance and excluding records with noise or missing data is required. Using a clean dataset, data mining algorithms allow to detect outliers and unusual records, but also to discover groups and to create regression functions to find relationships.

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APPENDIX A1: CALCULATIONS EXAMPLE DEPRECIATION PROFILES

This appendix lists the values calculated with the Straight Line Method, Declining Balance Method, Sum of the Years' Digits Method and Units of Activity Method.

The following basic data about a fictive locomotive is used:

- Value (new) = €1,000,000
- Value (residual) = €0
- Useful life = 10 years

A1.1 STRAIGHT LINE METHOD

The Straight Line Method uses a yearly depreciation charge of €100,000. This value is found using the formula presented in Equation 13. Table 39 presents the resulting values.

$$Yearly\ depreciation = \frac{Value\ (new) - Value\ (residual)}{Estimated\ useful\ life}$$

EQUATION 13: FORMULA STRAIGHT LINE METHOD

TABLE 39: DEPRECATION VALUES STRAIGHT LINE METHOD

YEAR	DEPRECIATION EXPENSE	RESIDUAL VALUE
0	-	€1,000,000
1	€100,000	€900,000
2	€100,000	€800,000
3	€100,000	€700,000
4	€100,000	€600,000
5	€100,000	€500,000
6	€100,000	€400,000
7	€100,000	€300,000
8	€100,000	€200,000
9	€100,000	€100,000
10	€100,000	-

A1.2 DECLINING BALANCE METHOD

For the Declining Balance Method, a depreciation percentage of 40% is used. The value of the yearly depreciation charge is calculated with Equation 14. Applying the Declining Balance Method returns the values listed in Table 40. The depreciation charge in year ten is the residual value in year nine to ensure that no residual value remains. The nature of the formula always requires such a correction.

$$Yearly\ depreciation = (Net\ book\ value - Value\ (residual)) \times\ Estimated\ depreciation\ rate$$

EQUATION 14: FORMULA DECLINING BALANCE METHOD

TABLE 40: DEPRECATION VALUES DECLINING BALANCE METHOD

YEAR	DEPRECIATION EXPENSE	RESIDUAL VALUE
0	-	€1,000,000
1	€400,000	€600,000
2	€240,000	€360,000
3	€144,000	€216,000
4	€86,400	€129,600
5	€51,840	€77,760
6	€31,104	€46,656
7	€18,662	€27,994
8	€11,197	€16,796
9	€6,718	€10,078
10	€10,078	-

A1.3 SUM OF THE YEARS' DIGITS METHOD

The Sum of the Years' Digits Method is based on the formula in Equation 15.

$$Yearly\ depreciation = \frac{Remaining\ useful\ life}{Sum\ of\ the\ year's\ digits} \times (Value\ (new) - Value\ (residual))$$

EQUATION 15: FORMULA SUM OF THE YEARS' DIGITS METHOD

Applying this formula to the fictive locomotive results in the yearly depreciation charges and residual values as presented in Table 41.

TABLE 41: DEPRECIATION VALUES SUM OF THE YEARS' DIGITS METHOD

YEAR	DEPRECIATION EXPENSE	RESIDUAL VALUE
0	-	€1,000,000
1	€181,818	€818.182
2	€163,636	€654,545
3	€145,455	€509,091
4	€127,273	€381,818
5	€109,091	€272,727
6	€90,909	€181.818
7	€72,727	€109,091
8	€54,545	€54,545
9	€36,364	€18,182
10	€18,182	-

A1.4 UNITS OF ACTIVITY METHOD

In contrast to the previous three methods, the Units of Activity Method is not time-based but activity-based. Equation 16 presents the formula that is used to calculate the yearly deprecation charges and residual values of the fictive locomotive.

$$Yearly\ depreciation = \big(Value\ (new) - Value\ (residual)\big) \times \frac{Amount\ of\ activity\ completed}{Est.total\ activity\ of\ asset}$$

EQUATION 16: FORMULA UNITS OF ACTIVITY METHOD

A varying number of kilometres is used with an average number of kilometres of 250,000 per year and a total number of kilometres of 2,500,000 for the estimated total activity during the locomotive's useful life. Table 42 presents the resulting values.

TABLE 42: DEPRECIATION VALUES UNITS OF ACTIVITY METHOD

YEAR	# KM / YEAR	DEPRECIATION EXPENSE	RESIDUAL VALUE
0	-	-	€1,000,000
1	300,000	€120,000	€880,000
2	0	€0	€880,000
3	400,000	€160,000	€720,000
4	200,000	€80,000	€640,000
5	100,000	€40,000	€600,000
6	400,000	€160,000	€440,000
7	300,000	€120,000	€320,000
8	100,000	€40,000	€280,000
9	500,000	€200,000	€80,000
10	200,000	€80,000	-

APPENDIX A2: LOCOMOTIVE DATA

This appendix gives insight in the original data collected for new-built and second-hand locomotives as included in spreadsheet Data_Locomotives.xlsx. Every line in the document represents a transaction of a new or second-hand vehicle. Every record informs about the transaction itself and provides technical details.

Year of deal, Year built & Age

The variable *Year of deal* represents the year in which the transaction took place and the variable *Year built* the year of construction. These two variables are used to determine the age of second-hand vehicles in years at the time of the transaction, according to Equation 17.

$$Age = Year\ of\ deal - Year\ built$$

EQUATION 17: AGE

Performance freight market & Performance passenger market

The variable *Performance freight market* is measured in billion tonne-kilometres and is used as an alternative economic indicator for earnings due to the different nature of the rail freight market compared to shipping and air transport. The variable *Performance passenger market* is measured in billion passenger-kilometres. Both variables cover the years 2004-2016.

For the performance of the rail freight market in the period 2004-2015, data about the performed number of tonne-kilometres is collected from Eurostat (2016a) for 27 countries. For the year 2015, two countries lacked data. For the year 2016, no data was available yet, so an estimation for the annual growth (1.2%) in the period 2014-2019 by SCI Verkehr (2016c) has been used to estimate the number of tonne-kilometres in 2016 and in 2015 for the two missing cases.

The performance of the passenger rail market is established for sixteen countries. Eurostat (2016b) lacked sufficient data for eleven countries also included for the rail freight market. Although the dataset is smaller, it contains a healthy mix of Western and Eastern European countries, as well as large and small countries. With no official values for 2016, the average annual growth percentage for the period 2004-2015 was used. The state of the rail freight and passenger rail market are not comparable in absolute terms, so their performance was indexed, using 2004 as the base year.

Region

The variable *Region*, represents the area where the vehicle is or will be operated. These regions are determined geographically and by the characteristics of their railway systems. For example, the Commonwealth of Independent States is a region based on its mainly 1520mm gauge network. In its market study for electric locomotives, SCI Verkehr determines seven regions: Europe, Asia, North America, Central and South America, the CIS countries, Africa/the Middle East and Australia/the Pacific (SCI Verkehr, 2016b). All entries for the variable *Region* follow this categorization.

Data for this research is limited to Europe, with exceptions for North Africa and the Middle East where rolling stock is used according to European standards. These exceptions include Iran, Israel, Morocco and Iran. Generally, their rail systems are highly developed and share many communalities with European railways (e.g. train protection systems, coupling design and train types). Similar price levels confirm that these transactions are in line with European deliveries.

Manufacturer, Manufacturer Country, Manufacturer Sub-region

The variable *Manufacturer* lists the name of the producer. *Manufacturer country* lists the country of production, according to the ISO 3166-I Alpha 2 code (International Organization for Standardization (ISO), 2016). *Manufacturer Sub-region* lists if the vehicle has been built in Western or Eastern Europe.

Type

The type designation of the rail vehicle as used by the manufacturer is listed by the variable *Type*.

Gauge

Gauge or track gauge is the spacing of the rails and is listed in millimetres. Rail vehicles are designed for a specific gauge, such as 1000 mm narrow, 1435 mm standard or 1520 mm broad gauge.

Axle arrangement & Number of axles

For locomotives, the axle arrangement (i.e. the configuration of the wheelsets) is listed, for freight wagons the number of axles. A translation of *Axle arrangement* in *Number of axles* is included for locomotives to create a uniform variable.

Different systems are in use to describe axle arrangements in a standardised way. In Europe, the UIC (International Union of Railways) classification system is most widely used. This system can describe the number of axles in general, the number of powered axles, the position of the bogies, the propulsion system and the number of sections of a rail vehicle. For instance: a Bo'Bo' is a vehicle with four driven axles (B), no non-powered axles, individually powered axles (o), two bogies (‘) and consisting of only one segment. The standardised UIC classification system is laid down in UIC leaflet 650 *Standard designation of axle arrangement on locomotives and multiple-unit sets* (UIC, 1983). Other classification systems include the AAR wheel arrangement system used in the United States of America and Canada, and the Whyte wheel arrangement system used in the United Kingdom.

Propulsion system

The *Propulsion system* denotes how a vehicle is powered. The most well-known types are diesel and electricity, but more specific forms exist. The data follow a tailor-made system, following industry innovations. Basic propulsion systems (i.e. electric, diesel-hydraulic, diesel-electric and diesel-mechanic) have been joined by hybrid systems, such as electro-diesel and multi-engine diesel. Table 43 presents the designators used in the original dataset to identify the different propulsion systems.

TABLE 43: PROPULSION SYSTEMS

DESIGNATION	DESCRIPTION
E	Electric propulsion
EDe	Electric propulsion with additional diesel engine
EnDe	Electric propulsion with n additional diesel engines
De	Diesel-electric propulsion, single-engine
nDe	Diesel-electric propulsion, multi-engine with n engines
nDh	Diesel-hydraulic propulsion, multi-engine with n engines
nDm	Diesel-mechanic propulsion, multi-engine with n engines

Power rating electric & Power rating diesel

The power rating of a locomotive is denoted in kW. It represents the power rating at the engine and not at wheel, as this is most commonly reported. A difference is made between a *Power rating electric* and a *Power rating diesel,* because both can be applicable for hybrid rail vehicles.

Emission compliance

The variable *Emission compliance* relates to the categories in emission legislation applicable for rail vehicles. Table 44 lists the five existing levels. Levels UIC-I and UIC-II are distinguished by UIC in leaflet 623 *Approval tests for diesel engines of motive power units* in 1999 (UIC, 2014). Subsequent stages are laid down in the category Rail Traction Engines of Directive EU 97/68/EC for Non-Road Mobile Machinery to further decrease carbon oxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PMx) by setting maximum levels (European Commission, 2016). EU 97/68/EC Stage III is harmonized with UIC Stage III and comprises of Stage IIIA and IIIB. The latter takes the place of Stage IV (DieselNet, 2016). Stage V has not gone into force yet.

TABLE 44: EMISSION STANDARDS RAIL ENGINES

EMISSION STANDARD	DATE INTO FORCE
UIC-I	Before 2003
UIC-II	2003
Stage IIIA	2006-2009
Stage IIIB	2012
Stage V	2021 (proposed)

Voltage system

Voltage system indicates which overhead or third-rail power systems electric or hybrid locomotives can use. Table 45 presents the most common systems used in Europe. Some locomotives can operate on multiple voltages, so records may contain combinations of voltage systems. Examples are modern AC locomotives (15+25), DC locomotives (1.5+3) or multisystem locomotives (e.g. 1.5+25 or 1.5+3+15+25).

TABLE 45: VOLTAGE SYSTEMS

VOLTAGE (KV)	TYPE OF CURRENT	NATURE OF POWER SYSTEM
0.75	DC	Third rail
1.5	DC	Overhead line
3	DC	Overhead line
15	AC	Overhead line
25	AC	Overhead line

Configuration

The *configuration* of a locomotive comprises of the countries a locomotive is configured to operate in. These countries are listed by their ISO 3166-I Alpha 2 country codes (International Organization for Standardization (ISO), 2016). A specific configuration does not imply that the vehicle is approved to operate in all countries, but that it has the required technical systems on board.

Speed

The variable *Speed* lists the maximum operating speed as determined by the manufacturer. It does not refer to the technical maximum speed of a vehicle, which is higher than its certified operating speed. The notation of speed is in km/h.

ETCS & ETCS Level

ETCS is a European train protection system and is part of ERTMS. It is designed to replace national systems to improve interoperability. Vehicles with on-board ETCS can run on specific lines equipped with the system, such as the Dutch Betuweroute or the Swiss Gotthard Base Tunnel. As of September 2009, trackside ETCS is mandatory for EU funded railway projects and *"Vehicles ordered after January 1 2012 or entering service after January 1 2015 must be equipped for ERTMS, though there are some exceptions for domestic and regional stock"* (Railway Gazette International, 2009).

The *ETCS Level* states the level of the on-board ETCS equipment. Not all vehicles have ETCS on board, but the most used systems are Level 1 and Level 2. ETCS is downward compatible, "i.e. a vehicle equipped with ETCS Level 2 may also travel on Level 1 lines, whereas a vehicle equipped with ETCS Level 1 cannot travel on Level 2 lines" (Siemens, 2015).

Level 1

The first level of the ETCS system uses a lineside electronic unit (LEU) to read the movement authority from the interlocking system and forwards this to transponders between the rails, the so-called Eurobalises. These balises transfer the information to the on-board ETCS computer when the train passes. The computer continuously monitors if the received speed limits are met and continuously calculates the braking curve based on the route ahead and train characteristics. All information is presented to the driver by means of cab signalling. If necessary, the system intervenes by applying the brakes until the movement authority is met again. Under Level 1, train positioning is performed by means of conventional detection loops or axle counters.

Level 2
In contrast to Level 1, the movement authority is continuously communicated to the train by GSM-R from a radio block centre. This centre is linked to the interlocking system. The function of the on-board ETCS computer is similar to Level 1, but additionally returns the position of the front of the train to the interlocking system. To confirm the train's position and train integrity, traditional detection loops and/or axle counters are used. Thanks to continuous contact with the interlocking system, fixed-point signals become unnecessary.

Level 3
ETCS Level 3 no longer uses traditional train positioning techniques such as detection loops or axle counters. All trains determine their own position, track occupation and train integrity. This data is continuously transmitted by GSM-R to a control centre that combines this information and determines up to which point the track has been cleared. The following vehicle is then granted a movement authority up to this point. Fixed blocks are no longer necessary thanks to the radio-based train spacing functionality.

 # (quantity), Transaction value total & Transaction value per piece
The variable *#* states per record how many vehicles of the same type were involved in the transaction. The total value of the deal is denoted as *Transaction value total.* Subsequently, the *Transaction value per piece* is found with Equation 18.

$$Transaction\ value\ per\ piece = \frac{Transaction\ value\ total}{\#}$$

EQUATION 18: TRANSACTION VALUE PER PIECE

Incl. maintenance & Maintenance period
Transactions concerning new rail vehicles may include a maintenance contract for several years, during which the producer provides additional servicing, maintenance and major overhaul tasks. If such a contract is included is denoted by the variable *Incl. maintenance*, the value of this variable is either yes or no. The *Maintenance period* lists the length of the contract period in years.

Revision & Year of last revision
Per record, the variable *Revision* lists yes or no. It indicates if a vehicle was in a valid maintenance regime at the time of the transaction. This is the case for new locomotives by default. When known, also the *Year of last revision* is listed to indicate how long the vehicle has been sidelined without an overhaul. The condition of a vehicle is included through its position in the maintenance cycle as this is more objective than the subjectively determined state of a vehicle (e.g. bad, average, very good, as new). Naturally, the state of a vehicle may still vary (e.g. with respect to the state of the paint and of non-essential parts). Furthermore, different parties' opinions may vary about the term 'state'. Moreover, several assets were sold at different price levels, based on the position within its maintenance regime. For example: the sale of type Lgjns container wagons for €11,250 per piece if in a valid regime and €8,500 per piece if not.

Industry professional B. Wagner of Beacon Rail Leasing (personal communication, July 19, 2016) has indicated that similar price differences apply to locomotives, as a main overhaul can easily cost €60,000. With respect to maintenance, four main factors are of influence:

- the ‘HU’-certificate (Hauptuntersuchung)
- the state of the (diesel) engines
- the state of the traction systems and motors
- the state of the wheels.

The dataset contains information about the presence of a ‘HU’-certificate, but does not consider other factors. Only for freight wagons, information about the axle diameter is available.

The Hauptuntersuchung is a main overhaul that takes place every six years according to German rolling stock legislation. The most recent ‘HU’-date is always visible on a vehicle. After six years, a vehicle loses its authorisation to run in normal service, but it is possible to extend this period by one year at a time up to eight years (Bundesministerium der Justiz und für Verbraucherschutz, 2016). Other countries using similar systems are Belgium (every eight years) and Switzerland (every six years). As a uniform European system lacks, it is impossible to consider all different national systems in a similar way, though some countries (e.g. The Netherlands) accept the German system as a proof of good maintenance. Therefore, it is only listed if a locomotive was at a valid point in its main overhaul cycle. The inclusion of the number of years since a vehicle’s last main revision was considered, but there was insufficient data to do so.

APPENDIX A3: FREIGHT WAGON DATA

This appendix gives insight in the original data for new and used freight wagons as included in spreadsheet Data_FreightWagons.xlsx. Several variables are similar as for locomotives, so only variables (with) specific (values) for freight wagons are mentioned.

Type

Type is the type designation of a wagon according to the UIC classification. This classification uses a system of letters referring to the most important technical characteristics. Every designation consists of an upper-case letter and several lower-case index letters. The upper-case letter indicates the class of wagon and construction type (regular or special). Lower-case letters describe main technical features and differ per class. Table 46 lists the wagon classes.

TABLE 46: FREIGHT WAGON CLASSES

WAGON CLASS	WAGON TYPE
E	Regular open wagon with high sides
F	Special open wagon with high sides
G	Ordinary covered wagon
H	Special covered wagon
I	Temperature-controlled wagon
K	Ordinary two-axle flat wagon
L	Special flat wagon with separate axles
O	Composite open wagon
R	Ordinary bogie flat wagon
S	Special bogie flat wagon
T	Wagon with opening roof
U	Special wagon
Z	Tank wagon
Source: UIC leaflet 438-2 (2004b)	

Approval

Wagon inscriptions indicate to what extent they can be used internationally. If *Approval* lists RIV / TEN, the wagon is certified for standard gauge lines in all countries except for the United Kingdom. RIV regulations governed the interoperability of freight and passenger wagons in predominantly Western and Central Europe from 1921 until 2007, when RIV was replaced by TEN according to Technical Specifications for Interoperability for rolling stock (DB Schenker Rail AG, 2011).

The TEN system includes several variants based on specific loading gauges for European railway lines: TEN G1, TEN GE and TEN CW (ERFA, UIC & UIP, 2016). However, the dataset is not that detailed and merely indicates whether the vehicle is RIV / TEN certified or not. If a wagon is certified for use on Eastern European or Asian railways, is indicated by the letters PGW. This Russian abbreviation stands for ‘Rules of Reciprocal Use of Wagons in International Traffic’ (DB Schenker Rail AG, 2011).

Length over buffers, Max. width & Height

The main measurements of a wagon are its maximum length (i.e. the *length over buffers*), maximum width (*Max. width)* and maximum height (*Max. height*). All are measured in millimetres. Not only do measurements relate to capacity, for many types they are important for the loading and unloading environment. The height of class E and class F wagons is often mentioned explicitly to ensure the height of the loading facility or the reach of the loading vehicle is sufficient.

Speed loaded & Speed unloaded

The variables *Speed loaded* and *Speed unloaded* list the approved speeds for wagons to travel in loaded or unloaded condition and are measured in km/h. Markings on the wagons indicate the maximum speed at various loads and/or on different national railway networks (UIC, 2004a). In case of differences between different countries, the highest (i.e. the technical maximum) speed is listed.

Two regimes are distinguished in UIC leaflet 432 (2008) that apply to most freight wagons:

- ‘s’ regime
- ‘ss’ regime

The ‘s’ regime states at which loads wagons may travel at 100 km/h with no particular operational restrictions. The ‘ss’ regime is similar, but has a maximum of 120 km/h. If the ‘ss’ regime states a maximum load of zero tonnes, 120 km/h is only allowed when unloaded. If the ‘ss’ regime does not apply, the maximum speed when empty is similar to the loaded speed under ‘s’ regime. If the maximum speed differs, the markings indicate this explicitly.

Tare weight

The variable *Tare weight* indicates the own weight of the wagon in kilograms.

Cargo capacity TEU, Cargo capacity m^3 & Cargo capacity cars

Cargo capacity TEU, *Cargo capacity m^3* and *Cargo capacity cars* indicate the capacity of specific wagon types. *Cargo capacity TEU* is used for class L, R and S wagons and identifies how many twenty feet containers can be carried. *Cargo capacity m^3* lists the volume available to hold a specific cargo type. This includes dry bulk (class E, F and T), piece goods and pallets (class H and L) and liquid bulk (class Z). *Cargo capacity cars* determines how many cars can be carried. In this dataset, this is only the case for class L wagons.

Cargo capacity general, Load limit A, B, C, D, E, F & G

Cargo capacity general is the maximum load a wagon can carry. The load limits of a wagon are listed per category of railway line. Every category corresponds to a permissible axle load (Table 47). In the dataset, the general cargo capacity and the load limit per load category are listed in kilograms.

TABLE 47: AXLE LOAD CATEGORIES

AXLE LOAD CATEGORY	MAX. PERMISSIBLE AXLE LOAD (T)
A	16
B	18
C	20
D	22.5
E	25
F	27.5
G	30
Source: DB Schenker Rail AG (2011)	

The maximum load per axle load category is calculated with Equation 19, in which *x* represents the category of railway line. Freight wagons always carry inscriptions with the maximum permissible axle loads. Not all wagons can be loaded up to the highest category due to tare weight limitations or technical limitations. Additionally, subcategories exist (e.g. B1, B2, C2 and D2) setting restrictions to the maximum vehicle mass per unit length, but these are not included in the dataset.

$$Load\ limit\ x = (Max. permissible\ axle\ load\ x\ \times number\ of\ axles) - Tare\ weight$$

EQUATION 19: LOAD LIMIT

Loadable length, loadable width & Loadable area

Loadable length is the maximum length and *Loadable width* the maximum width of the load in millimetres. *Loadable area* is the floor space in square metres.

Loadable width opening, Width bottom dump slides & Unloading system

The loadable width of the opening is mainly applicable for dry bulk wagons and is measured in millimetres, just like the width of the bottom dump slides used for unloading dry bulk (mainly class F and T wagons). The variable *Unloading system* lists the unloading method: mechanically, pneumatically or electrically.

Bogie type & Axle diameter

The most widely used bogie type is the Y25. Several variants exist with different axle weights, with or without braking equipment, for different speeds, loading gauges and spring types. Family members of the Y25 are the Y21, Y23, Y27, Y31, Y33 and Y37 (NB-Rail Association, 2015). Other types include the Tatravagonka TVP series (Tatravagonka, 2016a), G-series bogies (e.g. G56, G66, G691), K-series bogies (e.g. K16 and K17), bogies developed for DB and bogies developed for FS (OTIF, 2010).

Axle diameter, measured in millimetres, lists the diameter at the time of transaction. Three conditions are possible: new, used and worn. The diameter in new condition is the upper bound; the worn condition is the minimum diameter at which an axle needs to be replaced.

Brake type

As of March 2005, the types accepted by UIC for international traffic are those listed in Table 48.

TABLE 48: FREIGHT WAGON BRAKE TYPES

BRAKE TYPE	ABBREVIATION
Kunze-Knorr	Kk
Drolshammer	Dr
Bozic	Bo
Hildebrand-Knorr	Hik
Breda	Bd
Charmilles	Ch
Oerlikon	O
Knorr, type KE	KE
Westinghouse, type E	WE
Dako	DK
Westinghouse, type U	WU
Westinghouse, type A (approved until 1.1.2000 for new wagons)	WA
Davies and Metcalfe, Distributor DMD 3	DM
MZT HEPOS	MH
SAB-WABCO, Type SW 4/SW 4C/SW 4/3	SW
Distributor KE-483 (In position “483”, the brake meets the requirements for CIS networks)	KE 483
Source: UIC (2004a)	

APPENDIX A4: MARKET DATA

This appendix gives insight in the performance of the rail freight and passenger rail markets for the period 2004-2016, as registered by Eurostat for several EU member states and other countries on the European continent. Countries with missing data (i.e. not available, confidential or not applicable) have been excluded, resulting in datasets comprising of 27 countries and 16 countries respectively.

A4.1 PERFORMANCE RAIL FREIGHT MARKET

Table 49 presents the yearly number of tonne-kilometres. Values highlighted in bold are estimated values, using a projected annual growth of 1.2% for the period 2014-2019 by SCI Verkehr (2016c). The resulting indices reveal a market that has been relatively stable over the past decennium.

*TABLE 49: PERFORMANCE RAIL FREIGHT MARKET 2004-2016 (TONNE-KM * 10E6)*

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AT	18,757	18,957	20,980	21,371	21,915	17,767	19,833	20,345	19,499	19,278	20,494	20,266	***20,509***
CZ	15,092	14,866	15,779	16,304	15,437	12,791	13,770	14,316	14,267	13,965	14,574	15,261	***15,444***
DE	86,409	95,420	107,007	114,615	115,652	95,834	107,317	113,317	110,065	112,613	112,629	***113,981***	***115,348***
DK	2,321	1,976	1,892	1,779	1,866	1,700	2,239	2,614	2,278	2,449	2,455	2,273	***2,300***
EE	10,488	10,639	10,418	8,430	5,943	5,947	6,638	6,271	5,129	4,722	3,256	3,117	***3,154***
ES	12,436	11,585	11,541	11,237	10,971	7,806	8,913	9,451	9,458	9,338	10,385	11,131	***11,265***
FR	45,121	40,701	41,179	42,612	40,436	32,129	29,965	34,202	32,539	32,230	32,596	34,252	***34,663***
FI	10,105	9,706	11,060	10,434	10,777	8,872	9,750	9,395	9,275	9,470	9,597	8,468	***8,570***
GB	22,552	21,427	21,919	21,265	21,077	19,171	18,576	20,974	21,444	22,401	22,143	21,990	***22,254***
GR	592	613	662	835	786	552	614	352	283	237	311	***315***	***319***
HU	8,749	9,090	10,167	10,048	9,874	7,673	8,809	9,118	9,230	9,722	10,158	10,010	***10,130***
HR	2,493	2,835	3,305	3,574	3,312	2,641	2,618	2,438	2,332	2,086	2,119	2,184	***2,210***
IE	399	303	205	129	103	79	92	105	91	99	100	96	***97***
IT	22,183	22,761	24,151	25,285	23,831	17,791	18,616	19,787	20,244	19,037	20,157	20,781	***21,030***
LI	21	17	18	18	17	10	11	10	10	9	12	13	***13***
LT	11,637	12,457	12,896	14,373	14,748	11,888	13,431	15,088	14,172	13,344	14,307	14,036	***14,204***
LU	559	392	441	574	279	200	323	288	231	218	208	207	***209***
LV	18,618	19,779	16,831	18,313	19,581	18,725	17,179	21,410	21,867	19,532	19,441	18,906	***19,133***
NL	5,831	5,865	6,289	7,216	6,984	5,578	5,925	6,378	6,142	6,078	6,169	6,545	***6,624***
NO	2,845	3,182	3,351	3,502	3,621	3,506	3,496	3,574	3,489	3,383	3,539	3,498	***3,540***
PL	52,332	49,972	53,622	54,253	52,043	43,445	48,705	53,746	48,903	50,881	50,073	50,603	***51,210***
PT	2,282	2,422	2,430	2,586	2,549	2,174	2,313	2,322	2,421	2,290	2,434	2,688	***2,720***
RO	17,022	16,582	15,791	15,757	15,236	11,088	12,375	14,719	13,472	12,941	12,264	13,673	***13,837***
SE	20,856	21,675	22,271	23,250	22,924	20,389	23,464	22,864	22,043	20,970	21,296	20,583	***20,830***
SI	3,149	3,245	3,373	3,603	3,520	2,817	3,421	3,752	3,470	3,799	4,110	4,175	***4,225***
SK	9,702	9,463	9,988	9,647	9,299	6,964	8,105	7,960	7,591	8,494	8,829	8,439	***8,540***
TR	9,332	9,077	9,544	9,755	10,552	10,163	11,300	11,303	11,223	10,750	11,601	10,178	***10,300***
Sum	411,883	415,007	437,110	450,765	443,333	367,700	397,798	426,099	411,168	410,336	415,257	417,668	422,680
Index	100.0	100.8	106.1	109.4	107.6	89.3	96.6	103.5	99.8	99.6	100.8	101.4	102.6
Source: Eurostat (2016a)													

A4.2 Performance passenger rail market

Table 50 presents the yearly number of passenger-kilometers. Values highlighted in bold are estimated values, using the average annual growth over the period 2004-2015 (1.875%). Contrary to rail freight, the indices show a considerable growth for passenger rail over time.

*Table 50: Performance passenger rail market 2004-2016 (passenger-km * 10E6)*

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AT	7,865	8,095	8,262	8,514	9,687	9,620	9,713	10,172	10,606	11,188	11,345	11,433	***11,647***
CZ	6,580	6,667	6,922	6,898	6,773	6,472	6,559	6,669	7,196	7,512	7,644	8,125	***8,277***
EE	193	248	257	274	274	249	247	243	235	223	280	286	***291***
ES	20,238	21,047	21,519	21,236	23,336	22,742	22,044	22,645	22,170	23,660	24,915	26,018	***26,506***
GB	43,474	44,642	47,297	50,474	53,002	52,765	55,831	58,462	60,783	61,950	64,711	66,399	***67,644***
HR	1,169	1,227	1,322	1,573	1,769	1,802	1,711	1,457	1,080	935	917	941	***959***
IE	1,582	1,781	1,872	2,007	1,976	1,683	1,678	1,638	1,578	1,569	1,728	1,918	***1,954***
IT	45,577	46,144	46,439	45,985	45,767	44,404	43,349	45,944	45,753	47,707	48,881	51,121	***52,080***
LV	806	889	986	975	941	748	741	733	717	721	644	590	***601***
PL	18,430	17,882	18,240	19,524	19,762	18,128	17,485	17,633	17,110	16,453	15,479	17,024	***17,343***
PT	3,693	3,809	3,876	3,987	4,213	4,213	4,111	4,237	3,803	3,649	3,852	3,957	***4,031***
RO	8,633	7,960	8,065	7,417	6,877	5,975	5,248	5,044	4,518	4,352	4,971	4,910	***5,002***
SE	8,634	8,910	9,617	10,261	11,146	11,321	11,155	11,379	11,792	11,842	12,121	12,741	***12,980***
SI	695	716	724	740	765	773	729	689	659	679	620	628	***640***
SK	2,227	2,182	2,213	2,165	2,296	2,264	2,309	2,431	2,459	2,485	2,583	3,411	***3,475***
TR	5,237	5,036	5,277	5,553	5,097	5,374	5,491	5,882	4,598	3,775	4,393	4,828	***4,919***
Sum	175,033	177,235	182,888	187,583	193,681	188,533	188,401	195,258	195,057	198,700	205,084	214,330	218,349
Index	100.0	101.3	104.5	107.2	110.7	107.7	107.6	111.6	111.4	113.5	117.2	122.5	124.7
Source: Eurostat (2016b)													

APPENDIX A5: EX-ANTE LINEARITY CHECK

An important assumption behind multiple regression is the presence of linearity between the explanatory factors and the dependent variable. This appendix reviews to which extent linearity can be acceptably assumed.

A.5.1 LOCOMOTIVES

Figure 13 presents the relationship between *Age* and *Value*, which should be linear according to depreciation theory as established in Chapter 2. A decreasing nature is apparent, but the fairly low number of observations for second-hand vehicles with an age between 0 and approximately 25 years may cause an overestimation of vehicle value. This is mainly the result of the large share of second-hand shunters in the dataset, so the overestimation should not be too problematic in this case.

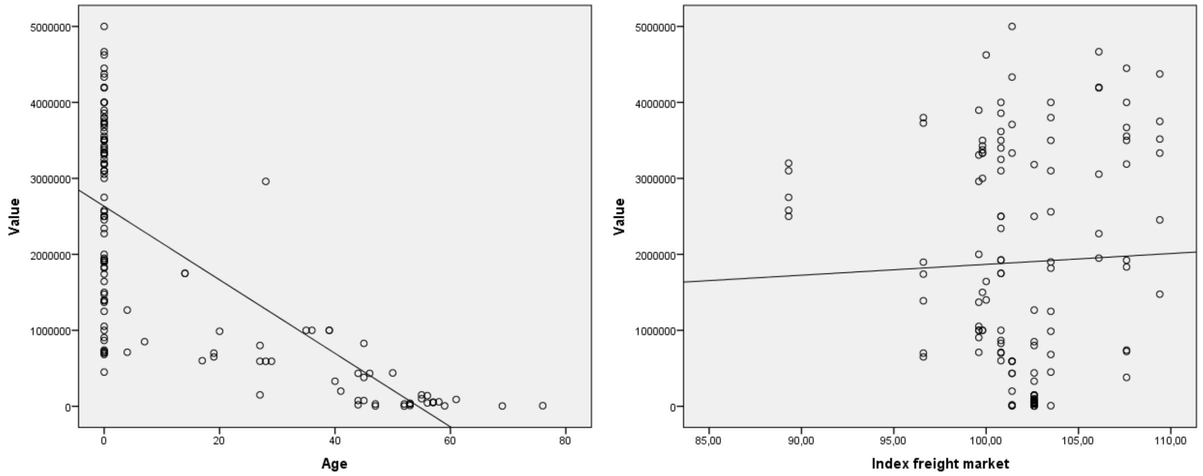


FIGURE 13: SCATTERPLOTS AGE AND VALUE (L) & INDEX FREIGHT MARKET AND VALUE (R)

As seen in Figure 13, a relationship between *Index freight market* and *Value* is not likely given the random observations around a fitted line that has a questionable slightly positive slope.

No clear relationship is visible between *Index passenger market* and *Value* (Figure 14), only a random pattern. Any relationship between the two is not expected.

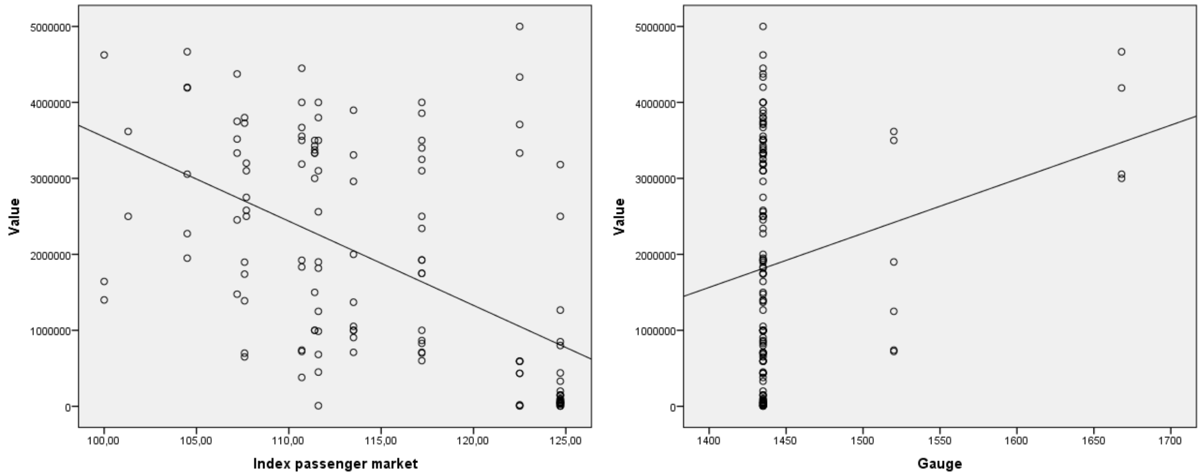


FIGURE 14: SCATTERPLOTS INDEX PASSENGER MARKET AND VALUE (L) & GAUGE AND VALUE (R)

Initially, the scatterplot for Gauge (Figure 14) indicates a failure to recognize groups of gauges, distinguishing three main groups: narrow, standard and broad gauge. Differences between 1435 mm standard, 1520 mm broad and 1668 mm broad gauge are visible. Less data for broad gauge vehicles questions the accuracy of the relationship. However, considering the many existing gauges (e.g. 1000, 1067, 1435, 1520, 1600, 1668 and 1676 mm), the variable is assumed to be of a metric nature.

A positive slope is visible despite the few points on the right. Representing true values, they are not outliers. Compared with practice, the positive slope is realistic, as broad gauge locomotives tend to be stronger. The spread for 1520 mm vehicles does not indicate a true difference, because the 1520 mm market is a large market too. After standard gauge, 1520 mm broad gauge is most commonly used worldwide, especially in the CIS-area and the Baltics. The 1668 mm Iberian gauge market is smaller and more specific, but synergy with Indian gauge (1676 mm) has seen second-hand transactions from Spain and Portugal to Chile and Argentina where 1676 mm is used too.

The scatterplot for *Number of axles* and *Value* (Figure 15) shows a fitted line with a positive slope. The plot also shows that linearity is in place, especially considering that locomotives with fewer axles (e.g. shunters) are generally lower-valued vehicles.

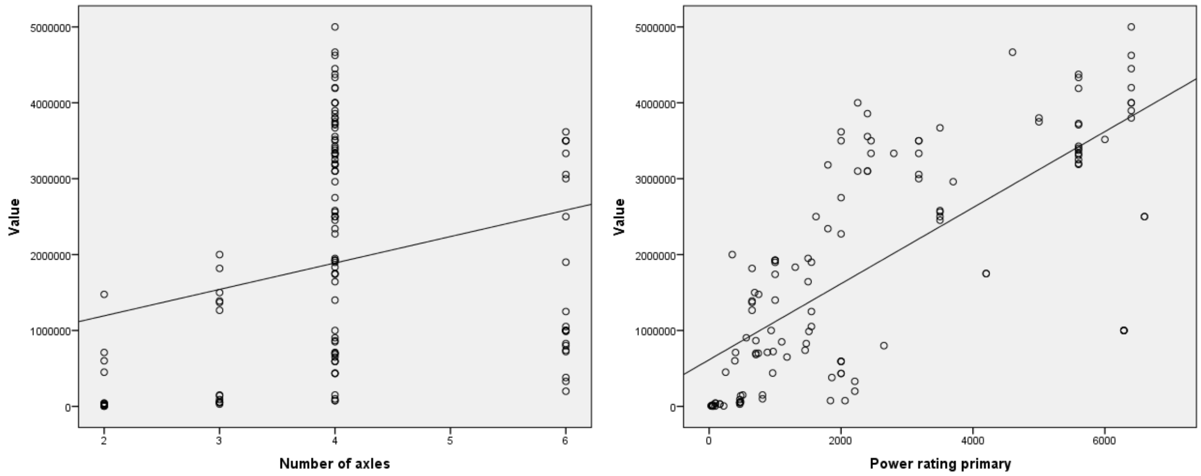


Figure 15: Scatterplots Number of axles and Value (l) & Power rating primary and Value (r)

At first sight, the positive slope of the fitted line between *Power rating primary* and *Value (*Figure 15) is as expected, but the linearity of the relationship may be questioned. It should be considered that there are less observations for high-powered second-hand vehicles than for new ones. Some of these observations are found well below the fitted line. As such, the danger of overestimating vehicle value based on power rating exists, but remains acceptable.

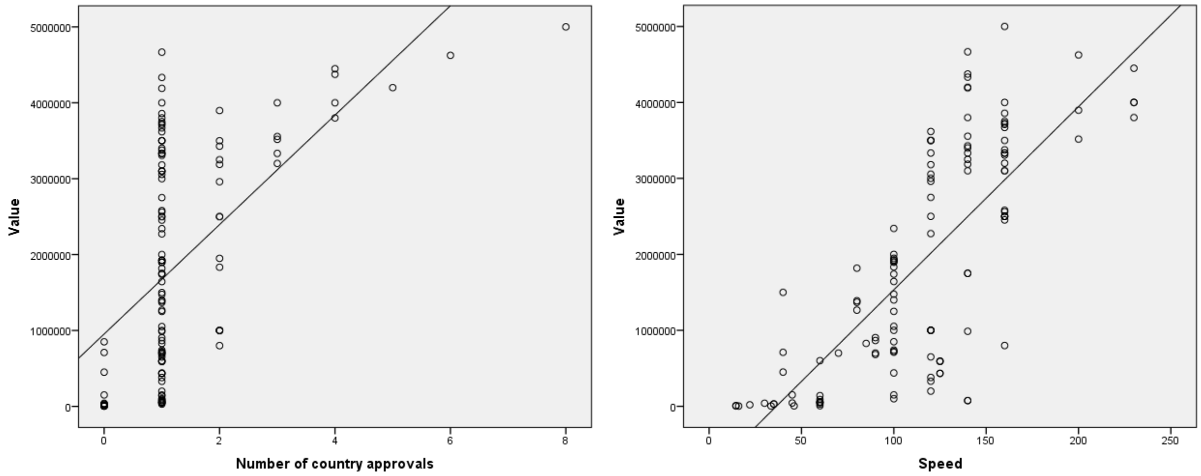


Figure 16: Scatterplots Number of country approvals and Value (l) & Speed and Value (r)

Figure 16 shows that the assumption of a linear relationship between *Number of country approvals* and *Value* holds reasonably well. Perhaps a steeper slope or a quadratic increase would be preferred here, as there is now the possibility of overestimating the value of locomotives without a nationwide approval and underestimating the value of locomotives with more than two country approvals.

The relationship between *Speed* and *Value* (Figure 16) can be assumed linear, as the fitted line matches the pattern in the scatterplot quite well. But, there is room for a positive non-linear relationship, which increases in a quadratic way.

The scatterplot for *Number of diesel engines* and *Value* (Figure 17) shows an unexpected slope of the fitted line. Where a positive slope would be expected, a negative is visible. Despite the slope of the line, the true shape of the relationship cannot be fully distinguished.

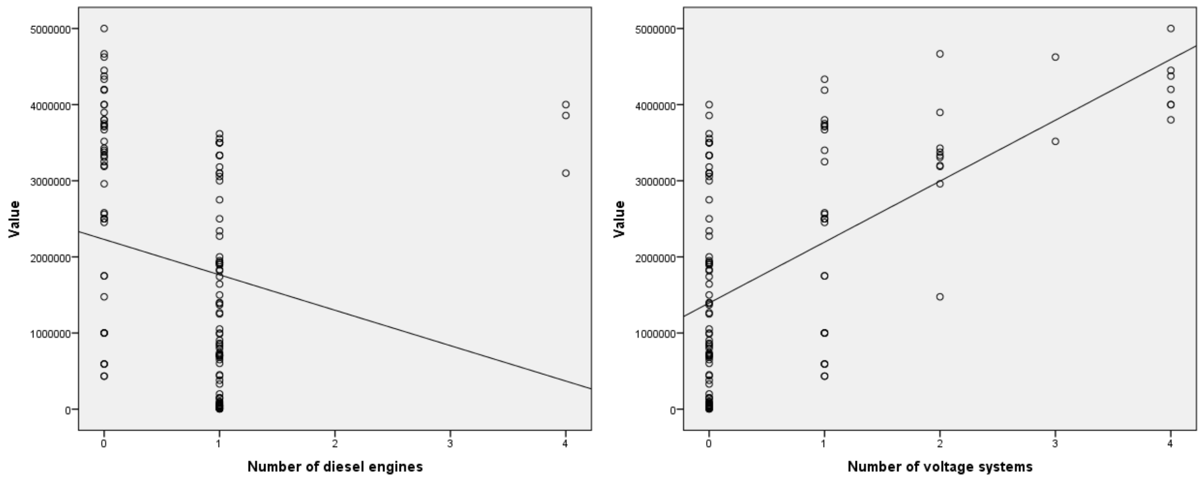


Figure 17: Scatterplots Number of diesel engines and Value (l) & Number of voltage systems and Value (r)

Figure 17 presents the scatterplot for *Number of voltage systems* and *Value*. Although the intercept with the y-axis would be expected to be a bit higher at first sight, the plot shows that a reasonable linear relationship between the two variables can be assumed.

A.5.2 Freight wagons

The negative relationship between *Age* and *Value* (Figure 18) is reasonably linear – in line with depreciation theory. Note the possibility of overestimating value for wagons aged between 0 and circa 25 years. A non-linear, decreasing relationship would cover this.

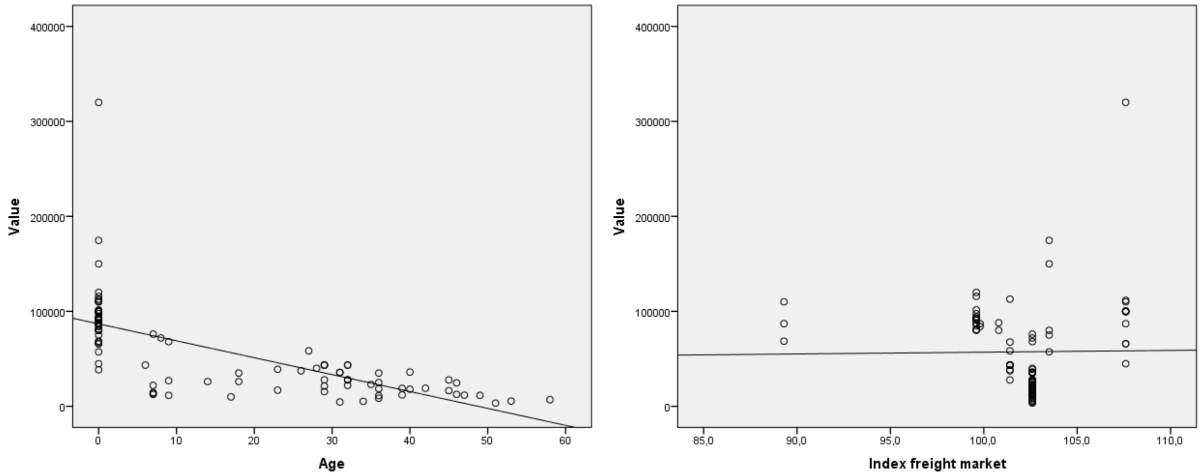


Figure 18: Scatterplots Age and Value (l) & Index freight market and Value (r)

The scatterplot of the relationship between *Index freight market* and *Value* (Figure 18). No clear relationship is apparent.

The scatterplot for *Number of axles* and *Value* (Figure 19) and shows a more clear linear relationship between the two variables. The positive direction of the relationships is as expected.

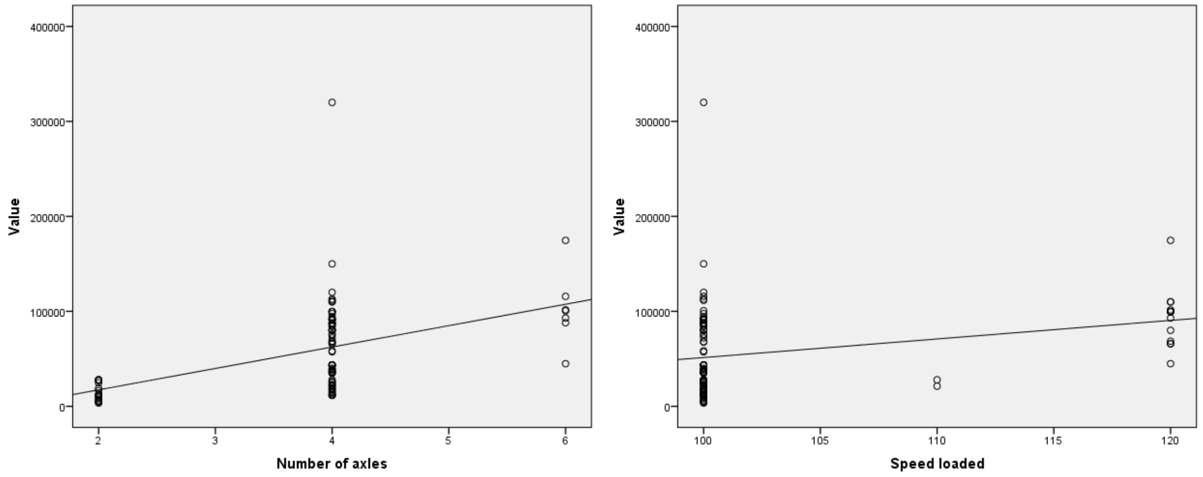


FIGURE 19: SCATTERPLOTS NUMBER OF AXLES AND VALUE (L) & SPEED LOADED AND VALUE (R)

Figure 19 presents the scatterplot for the variables *Speed loaded* and *Value*. Relatively high values for wagons with higher maximum operating speeds when loaded cause a slightly positive relationship between the two variables. Despite a lack of observations for intermediate maximum speeds, the relationship can be assumed to be sufficiently linear in this case.

Similar to the variables *Speed loaded* and *Value*, a slightly positive relationship between *Speed unloaded* and *Value* is observed in Figure 20. Again, it is safe to assume the relationship between the two variables is linear.

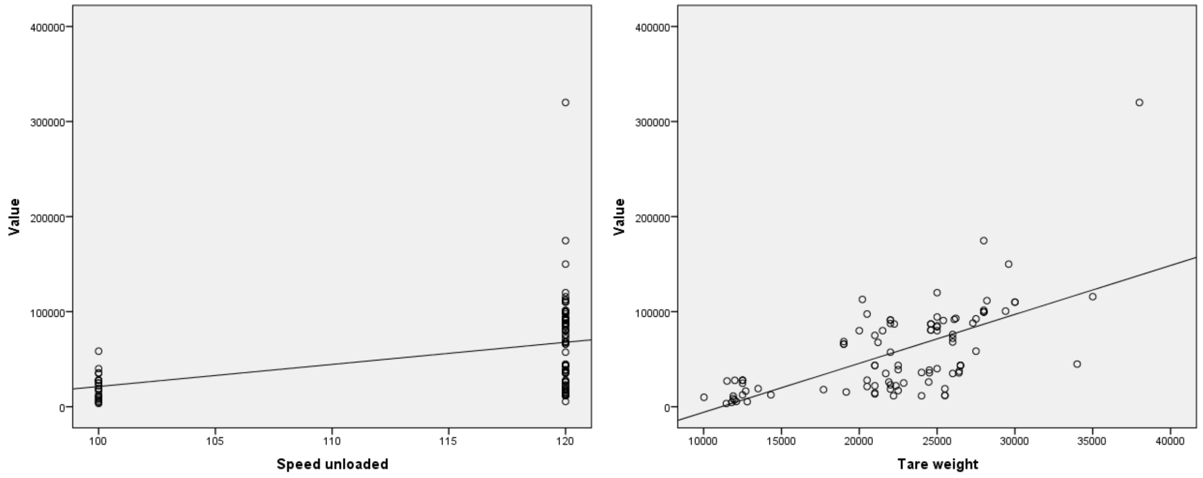


FIGURE 20: SCATTERPLOTS SPEED UNLOADED AND VALUE (L) & TARE WEIGHT AND VALUE (R)

As Figure 20 shows, a positive and linear relation between *Tare weight* and *Value* the two variables exists.

Figure 21 shows that the assumption of linearity between *Capacity general* and *Value* can safely be made, despite two outlying observations. A clear positive relation between the two variables exists.

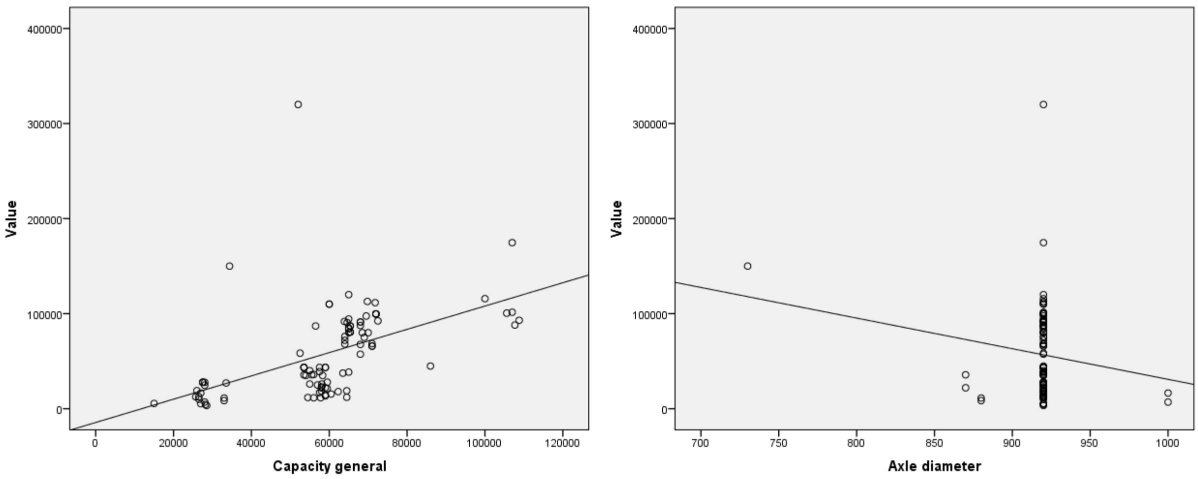


FIGURE 21: SCATTERPLOTS CAPACITY GENERAL AND VALUE (L) & AXLE DIAMETER AND VALUE

The previous relationships between the several metric explanatory variables are more apparent, but this is not immediately the case for *Axle diameter* (Figure 21). The large number of observations around the standard axle diameter of 920 mm make the nature of the relationship more difficult to determine. The outlying value to the left is not a rarity, as it concerns a high-value car transporter. Car transporters and wagons for ‘Rollende Landstrasse’ operations generally have smaller diameters but higher values. Despite the high uncertainty, the relationship is not considered to be fully inappropriate.

APPENDIX A6: CODING DUMMY VARIABLES

This appendix gives insight in the coding schemes used for the various dummy variables.

A6.1 GENERAL VARIABLES

TABLE 51: CODING MANUFACTURER EASTERN EUROPE

MANUFACTURER SUB-REGION	DUMMY - MANUFACTURER EASTERN EUROPE
Western Europe	0
Eastern Europe	1

TABLE 52: CODING NO REVISION

REVISION?	DUMMY - NO REVISION
Yes	0
No	1

A6.2 LOCOMOTIVES

TABLE 53: CODING SECTOR SHUNTER

SECTOR	DUMMY - SECTOR SHUNTER
Mainline	0
Shunter	1

TABLE 54: CODING ELECTRIC PROPULSION

PROPULSION CATEGORY	DUMMY - ELECTRIC PROPULSION
Diesel	0
Electric	1

TABLE 55: CODING ETCS L1 AND ETCS L2

ETCS CATEGORY	DUMMY - ETCS L1	DUMMY - ETCS L2
n/a	0	0
ETCS L1	1	0
ETCS L2	0	1

A6.3 FREIGHT WAGONS

TABLE 56: CODING FREIGHT WAGON SECTORS

SECTOR	DUMMY - SECTOR LIQUID BULK	DUMMY - SECTOR BREAK-BULK	DUMMY - SECTOR INTERMODAL	DUMMY - SECTOR COILS/PLATES	DUMMY - SECTOR CARS
Dry bulk	0	0	0	0	0
Liquid bulk	1	0	0	0	0
Break-bulk	0	1	0	0	0
Intermodal	0	0	1	0	0
Coils/plates	0	0	0	1	0
Cars	0	0	0	0	1

TABLE 57: CODING BOGIE FAMILY Y25 AND BOGIE FAMILY OTHER

BOGIE FAMILY	DUMMY - BOGIE FAMILY Y25	DUMMY - BOGIE FAMILY OTHER
n/a	0	0
Y25	1	0
Other	0	1

TABLE 58: CODING BRAKE FAMILY OERLIKON AND BRAKE FAMILY OTHER

BRAKE FAMILY	DUMMY - BRAKE FAMILY OERLIKON	DUMMY - BRAKE FAMILY OTHER
Knorr	0	0
Oerlikon	1	0
Other	0	1

APPENDIX A7: MODEL SPECIFICATION AND DISCUSSION OF INTERMEDIATE RESULTS

A7.1 LOCOMOTIVES

First, it is necessary to gain insight into the influence of a basic set of determinants on value. Gradually, this base model is expanded to a more comprehensive model until the increase in the value of the adjusted coefficient of determination (adjusted R^2) becomes so small that adding additional variables is not worthwhile. While extending the models, an approach is followed based on the theory as established in Chapter 2.

A7.1.1 MODEL SPECIFICATION

Equation 20 shows the initial model, which includes the factors *Age, Index passenger market* (*Index*$_{pax}$) and *Power rating primary* (*Power*$_{primary}$) as notions of the broad explanatory factors *Age*, *Earnings* and *Features*.

$$Value = b_0 + b_1 * Age + b_2 * Index_{pax} + b_3 * Power_{primary} + \varepsilon$$

EQUATION 20: LOCOMOTIVES - MODEL 1

As the results in Table 59 for Model 1 show, the *Index*$_{pax}$ is not significant. This outcome is not surprising as it could already be established that the correlation between this variable and *Value* was not as expected. Furthermore, its strong correlation with *Age* allows its exclusion. *Speed* is added as a second technical variable (Equation 21).

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + \varepsilon$$

EQUATION 21: LOCOMOTIVES - MODEL 2

In addition to the previous model, Model 3 includes another general technical variable, namely *Number of countries* (*No*$_{country}$), representing the theoretical influence of safety systems on value. This influence not only has a financial nature, but is also a measure of remarketing flexibility through the notion of asset specificity.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_5 * No_{country} + \varepsilon$$

EQUATION 22: LOCOMOTIVES - MODEL 3

Model 3 is expanded into a fourth model by adding general technical variables of a non-metric nature. First, the influence of on-board ETCS is researched, again with the theory of asset-specificity in mind. *No*$_{country}$ now lacks, as it is not significant.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_6 * ETCS_{L1} + b_7 * ETCS_{L2} + \varepsilon$$

EQUATION 23: LOCOMOTIVES - MODEL 4

The second variable to be added is the dummy *No revision* (*Rev*$_{no}$) to check whether it makes a significant difference in value if a vehicle is not in a valid maintenance regime. The dummy variable *ETCS*$_{L1}$ is excluded, because it does not return a significant result.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_7 * ETCS_{L2} + b_8 * Rev_{no} + \varepsilon$$

EQUATION 24: LOCOMOTIVES - MODEL 5

It is interesting to look at the effects of variables not directly related to market or technical characteristics. The dummy variable Man_{east} is included to check for differences between locomotives produced in Eastern and Western Europe.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_7 * ETCS_{L2} + b_8 * Rev_{no} + b_9 * Man_{east+\,\varepsilon} + \varepsilon$$

EQUATION 25: LOCOMOTIVES - MODEL 6

Now, it is researched whether the propulsion system is of influence on locomotive value. This is done by adding dummy variable $Prop_{elec}$, resulting in Model 7. With this variable, it is possible to find out whether electric locomotives should be valued differently than diesel locomotives.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_7 * ETCS_{L2} + b_8 * Rev_{no} + b_9 * Man_{east} + b_{10} * Prop_{elec} + \varepsilon$$

EQUATION 26: LOCOMOTIVES - MODEL 7

When looking at the results, adding the propulsion type does not get the result one would expect based on the theory, as electrics and diesel locomotives are expected to have different economics. Note that the adjusted R^2 remains at 81.9%, indicating that this model does not estimate vehicle value better than the previous model. Instead of the variable $Prop_{elec}$, the variable $Sector_{shunt}$ is now added to research whether it makes a difference to valuate a mainline or shunting locomotive. This model is shown in Equation 27.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_7 * ETCS_{L2} + b_8 * Rev_{no} + b_9 * Man_{east} + b_{11} * Sector_{shunt} + \varepsilon$$

EQUATION 27: LOCOMOTIVES - MODEL 8

$Sector_{shunt}$ is not significant at the 0.05 level and the significance of Rev_{no} decreases with every extra variable. With 82.3%, the model's adjusted R^2 increases.

Model 8 (Equation 27) is the final model built using a mix of intuition and the theoretical knowledge from Chapter 2. For Model 9 (Equation 28), the Stepwise function of SPSS is used, which automatically adds new variables until the increase in adjusted R^2 becomes too small to justify adding further variables to the regression equation.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_7 * ETCS_{L2} + b_9 * Man_{east} + b_{11} * Sector_{shunt} + \varepsilon$$

EQUATION 28: LOCOMOTIVES - MODEL 9

The results for Model 9 present a six-variable model that includes Age, $Power_{primary}$, $Speed$, $ETCS_{L2}$, Man_{east} and $Sector_{shunt}$. As the Stepwise method only considers the strongest relationships, it is not surprising that it does not consider if a vehicle was in a valid maintenance regime. This variable was included based on theoretical underpinnings, but its significance decreased from Model 6. Model 9 includes only those variables selected in the model building process.

$$Value = b_0 + b_1 * Age + b_3 * Power_{primary} + b_4 * Speed + b_7 * ETCS_{L2} + b_9 * Man_{east} + b_{11} * Sector_{shunt} + b_{13} * Gauge + \varepsilon$$

EQUATION 29: LOCOMOTIVES - MODEL 10

Model 10 (Equation 29) is also built using the Stepwise function, but now all possible determinants are considered. Interestingly, the inclusion of $Gauge$ raises the adjusted R^2 to 83.3%, the highest result up until now. This seems reasonable, as the model is not to explain value precisely. There is always an error, because of specific considerations during the transaction, influencing the final transaction value. For example, minor condition related influences and external influences such as spare part availability. Moreover, minor data errors, for example caused by rounding values for reasons of convenience or for confidentiality and typing errors in publication, are always possible.

A7.1.2 Results

This section presents the results of the eleven regression models specified in Section 4.2.1 and a more detailed interpretation. Models 1-6 are listed in Table 59, Models 7-10 in Table 60. Collinearity statistics for all models are included in Appendix A8 and the full results for the final model in Appendix A9.

Table 59: Locomotives - Results - Pt. 1

Model	**1**		**2**		**3**		**4**		**5**		**6**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**
Age	-.503	.000	-.478	.000	-.476	.000	-.470	.000	-.371	.000	-.423	.000
Index passenger market	-.043	.458	---	---	---	---	---	---	---	---	---	---
Power rating primary	.512	.000	.384	.000	.344	.000	.364	.000	.390	.000	.352	.000
Speed			.192	.000	.179	.022	.193	.012	.170	.023	.185	.008
Number of countries					.080	.160	---	---	---	---	---	---
Non-metric												
ETCS L1							-.012	.775	---	---	---	---
ETCS L2							.107	.015	.104	.015	.103	.009
No revision									.-141	.018	-.104	.060
Manufacturer Eastern Europe											-.183	.000
N	128		128		128		128		128		128	
Adj. R^2	75.9%		77.0%		77.2%		77.8%		78.7%		81.9%	

Model 1 explains 75.9% of the variance in *Value*. The regression coefficients reveal a strong negative relation between *Age* and *Value*, completely as expected based on the established theory. The contrary applies to *Power rating primary*, which has a strong positive relation with value. No significant relation between the state of the passenger market and value is found. Although locomotives may have a double function (i.e. passenger and freight operations), there is an explanation for this with respect to the passenger transport market. For multiple units, Metz & Radstake (2013) already found that the effects on vehicle acquisition of the economic crisis of 2008 were hardly visible because of the launch of new passenger rail franchises driven by liberalisation of the market. A second explanation may lie in the fact that there is a trend towards using multiple units on passenger services instead of locomotive-hauled stock for efficiency reasons.

Not further considering the effects of the state of the passenger rail market, but adding *Speed* instead results in Model 2. An increase of 1.1% in adjusted R^2 to 77.0% is witnessed and *Speed* is highly significant. It has a considerable positive effect on value, despite not showing the strongest relation of the variables. This relevance of vehicle speed is also seen in practice: locomotives designed for higher speeds require specific, more expensive, technological solutions, such as bogies with better running characteristics.

Model 3 includes all variables of Model 2 and sees the variable *Number of countries* added. However, no significant relationship is found and the increase in Adjusted R^2 is only low, which is not as anticipated for several reasons. As determined in the qualitative part of this research, the theory of asset specificity describes that when an asset is not easily re-used in different operational settings, its value becomes lower. Moreover, as Metz & Radstake (2013) determine, certification of rail vehicles in other countries is costly and time-consuming. Therefore, locomotives approved for operations in multiple countries should have a higher market value than those with limited operational flexibility.

Model 4 leaves *Number of countries* aside, but instead examines the effects of on-board ETCS Level 1 or Level 2. In contrast to ETCS Level 2, no significant relation is found for ETCS Level 1. Comparing this to Model 2, which does not include *Number of countries* as a variable, a considerable increase in the value of the adjusted R^2 is realized (0.8%). Although it is partly the result of only few observations of locomotives equipped with ETCS Level 1, this result does correspond with practice. The reason for this is not merely financial. ETCS Level 2 offers more flexibility through downward compatibility of the system, allowing vehicles to use both ETCS Level 1 and Level 2 equipped lines. Vehicles with ETCS Level 1 on board may not operate on Level 2 railways, which results in operational restrictions.

Table 60: Locomotives - Results - Pt. 2

Model	**7**		**8**		**9**		**10**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**B**	**Sig.**	**β**	**Sig.**
Age	-.420	.000	-.456	.000	-.519	.000	-.495	.000
Index passenger market	---	---	---	---	---	---	---	---
Power rating primary	.408	.000	.338	.000	.320	.000	.296	.000
Speed	.182	.009	.267	.001	.293	.000	.337	.000
Number of countries	---	---	---	---	---	---	---	---
Gauge	---	---	---	---	---	---	.119	.002
Non-metric								
ETCS L1	---	---	---	---	---	---	---	---
ETCS L2	.100	.011	.100	.010	.102	.010	.112	.003
No revision	-.098	.082	-.084	.132	---	---	---	---
Manufacturer Eastern Europe	-.177	.000	-.171	.000	-.177	.000	-.175	.000
Electric propulsion	-.061	.402	---	---	---	---	---	---
Sector shunter			.110	.067	.128	.031	.154	.008
Interaction electric propulsion and sector					---	---	---	---
N	128		128		128		128	
Adj. R^2	81.9%		82.3%		82.1%		83.3%	

Model 5 shows an increase in adjusted R^2 value of 0.9% to 78.7% after adding *No revision* and the negative influence on value is significant. This is also found in practice. Vehicles are sold at a lower price when in need of (heavy) maintenance.

Adding the dummy variable Man_{east} raises the adjusted R^2 of Model 6 to 81.9%, which is considerably higher than for previous models. A significant negative relation is found, showing that vehicles built by Eastern European manufacturers tend to be valued lower than vehicles built by Western European *producers*. Interestingly, the variable *No revision* is not significant anymore, albeit only just.

Model 7 shows no improvement in explained variance compared to Model 6, whilst, against the expectations, the variable $Prop_{elec}$ is not significant. The negative sign of the relationship may indicate the effect of asset specificity, as diesel locomotives are more easily used in different operational areas, as they are not limited by network dependent factors such as overhead power.

A slight improvement in explained variance, caused by the dummy variable $Sector_{shunt}$, is found for Model 8 with an adjusted R^2 of 82.3%. This variable is not significant at the 0.05 level, albeit only just. This indicates that there could be a difference in valuation between these groups of locomotives, but that the current dataset does not support it. The values of shunting locomotives are corrected with a positive sum. This indicates, corrected for other variables, shunters hold their value better over time.

Using the Stepwise function, the software does the work in Model 9 and adds the variables that have the strongest relation with *Value*. Only variables used in the theory-based approach for Model 1-8 are considered. A six-variable model covering the broad explanatory factors *Sector*, *Age* and *Technical features,* as well as a rail specific variable, is the result. Although supported by theory, *Number of countries* and *No revision* lack. The model has a good adjusted R^2 value of 82.1%.

Applying the Stepwise method to all metric variables for which the correlations have been calculated, results in Model 10. This expands Model 9 with *Gauge*, which has a significant positive relation with value. This means that the broader the gauge, the higher the value of the locomotive. This relation could have been anticipated beforehand, as narrow gauge railways are relatively rare compared to standard and broad gauge railway systems. As result, standard and broad gauge vehicles can be remarketed more easily. This final stepwise model, consisting of seven variables, has the highest adjusted R^2 value of 83.3%, but lacks some variables that should be included according to theory.

A7.2 FREIGHT WAGONS

A similar approach is used by building a model based on the qualitative findings from Chapter 2. Subsequently, the resulting models are compared to models built using the Stepwise approach.

A7.2.1 MODEL SPECIFICATION

The basic setup of freight wagon Model 1 is presented in Equation 30. It includes *Age, Index freight market* ($Index_{freight}$) and *Capacity general* ($Cap_{general}$) as notions of the broad explanatory factors *Age*, *Earnings* and *Capacity*. As such, the model covers both market and technical related variables.

$$Value = b_0 + b_1 * Age + b_2 * Index_{freight} + b_3 * Cap_{general} + \varepsilon$$

EQUATION 30: FREIGHT WAGONS - MODEL 1

Based on the found correlations, the outcomes in Table 61 are both surprising and unsurprising. Unsurprisingly, $Index_{freight}$ is not significant, so it is not further considered. Surprisingly, $Cap_{general}$ is not significant too, despite a good correlation with *Value*. The many strong correlations between explanatory variables are troublesome, so a slightly different approach is followed than for locomotives. All metric variables are added to check for multicollinearity by identifying high Variance Inflation Factor (VIF) values. This model is presented in Equation 31.

$$\begin{aligned} Value = b_0 + b_1 * Age + b_2 * Index_{freight} + b_3 * Cap_{general} + b_4 * No_{axle} + b_5 * Speed_{loaded} \\ + b_6 * Speed_{unloaded} + b_7 * Weight_{tare} + b_8 * Diameter_{axle} + \varepsilon \end{aligned}$$

EQUATION 31: FREIGHT WAGONS - MODEL 2

Number of axles (No_{axle}) and $Cap_{general}$ have high VIF values of 22.215 and 18.042 respectively. With a value of 4.338, the VIF value for *Tare weight* ($Weight_{tare}$) is relatively high too. This indicates that multicollinearity indeed exists. The Stepwise function is used to determine those variables that have the strongest relationship with value and that are good alternatives for the variables with strong interdependencies. Equation 32 presents the resulting model.

$$Value = b_0 + b_1 * Age + b_4 * No_{axle} + b_7 * Weight_{tare} + \varepsilon$$

EQUATION 32: FREIGHT WAGONS - MODEL 3

Subsequently, Model 3 is expanded with non-metric technical variables. A first variable to be added is *Bogie family*, represented through the dummy variables $Bogie_{Y25}$ and $Bogie_{other}$.

$$Value = b_0 + b_1 * Age + b_4 * No_{axle} + b_7 * Weight_{tare} + b_9 * Bogie_{Y25} + b_{10} * Bogie_{other} + \varepsilon$$

EQUATION 33: FREIGHT WAGONS - MODEL 4

The results in Table 62 show that $Bogie_{Y25}$ is highly and $Bogie_{other}$ almost significant. However, No_{axle} is not significant anymore. This is logical, as there is overlap between the two. Therefore, this variable is no longer considered. In a next step, Model 4 is expanded with the variable *Brake family*, using the dummy variables $Brake_{oerlikon}$ and $Brake_{other}$ to research whether different brake systems have an influence on wagon value. The reference category is the Knorr type KE braking system.

$$Value = b_0 + b_1 * Age + b_7 * Weight_{tare} + b_9 * Bogie_{Y25} + b_{10} * Bogie_{other} + b_{11} * Brake_{oerlikon} + b_{12} * Brake_{other} + \varepsilon$$

Equation 34: Freight wagons - Model 5

Interestingly, no significant influence on wagon value is found between wagons with different brake systems, even though $Brake_{oerlikon}$ is very close to significance. A next step is to research whether it differs if a wagon is in a valid maintenance regime or not. This is done by adding the variable Rev_{no}.

$$Value = b_0 + b_1 * Age + b_7 * Weight_{tare} + b_9 * Bogie_{Y25} + b_{10} * Bogie_{other} + b_{13} * Rev_{no} + \varepsilon$$

Equation 35: Freight wagons - Model 6

It is also of interest if the manufacturer is of influence. Similar to locomotives, Western and Eastern European producers are distinguished with the Western European manufacturer as the reference category. The addition of Man_{east} is shown in Equation 36.

$$Value = b_0 + b_1 * Age + b_7 * Weight_{tare} + b_9 * Bogie_{Y25} + b_{10} * Bogie_{other} + b_{13} * Rev_{no} + b_{14} * Man_{east} + \varepsilon$$

Equation 36: Freight wagons - Model 7

Finally, it is of interest whether differences exist between the six wagon sectors. With dry bulk wagons as the reference category, five dummy variables are added for the sectors liquid bulk, break-bulk, intermodal, coils/plates and cars (Equation 37).

$$Value = b_0 + b_1 * Age + b_7 * Weight_{tare} + b_9 * Bogie_{Y25} + b_{10} * Bogie_{other} + b_{13} * Rev_{no} + b_{14} * Man_{east} + b_{15} * Sector_{liquid} + b_{16} * Sector_{break} + b_{17} * Sector_{intermodal} + b_{18} * Sector_{coils} + b_{19} * Sector_{cars} + \varepsilon$$

Equation 37: Freight wagons - Model 8

As for locomotives, the results of the final model built using theory-based approach are compared to those of a model built with the Stepwise function. Model 9 features several different variables than Model 8 (Equation 38).

$$Value = b_0 + b_1 * Age + b_3 * Cap_{general} + b_4 * No_{axle} + b_7 * Weight_{tare} + b_8 * Diameter_{axle} + b_{12} * Brake_{other} + b_{13} * Rev_{no} + b_{19} * Sector_{cars} + \varepsilon$$

Equation 38: Freight wagons - Model 9

Model 9 features a combination of variables, related to the broad explanatory factors *Age, Capacity, Features, Sector and Other*. Only the broad explanatory factor *Earnings* lacks. However, very high multicollinearity exists due to the inclusion of both $Capacity_{general}$ and No_{axle}. The Stepwise function is used again to estimate a model, excluding No_{axle}. The resulting model is presented in Equation 39.

$$Value = b_0 + b_1 * Age + b_3 * Cap_{general} + b_8 * Diameter_{axle} + b_{13} * Rev_{no} + b_{16} * Sector_{break} + b_{19} * Sector_{cars} + \varepsilon$$

Equation 39: Freight wagons - Model 10

A7.2.2 RESULTS

This section presents the results of the ten regression models for freight wagons and provides a more detailed interpretation. Models 1-5 are listed in Table 61, Models 6-10 in Table 62. Collinearity statistics are included in Appendix A8.

TABLE 61: FREIGHT WAGONS - RESULTS - PT. 1

MODEL	**1**		**2**		**3**		**4**		**5**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**
Age	-.614	.000	-.417	.000	-.523	.000	-.530	.000	-.498	.000
Index freight market	.070	.352	-.010	.883	---	---	---	---	---	---
Capacity general	.121	.211	-.557	.042	---	---	---	---	---	---
Number of axles			-.898	.004	-.349	.004	-.094	.500	---	---
Speed loaded			.029	.689	---	---	---	---	---	---
Speed unloaded			-.069	.443	---	---	---	---	---	---
Tare weight			.784	.000	.655	.000	.584	.000	.502	.000
Axle diameter			-.088	.235	---	---	---	---	---	---
Non-metric										
Bogie family Y25							-.292	.002	-.333	.000
Bogie family other							-.141	.058	-.175	.012
Brake family Oerlikon									-.117	.077
Brake family other									.041	.512
N	98		98		98		98		98	
Adj. R^2	46.7%		60.7%		60.2%		63.3%		64.3%	

In Model 1 *Age* is the only significant and the most important factor. A regression model with *Age* alone would result in an Adjusted R^2 value of 46.4% when tested separately, adding to its importance. A direct relation with the state of the freight market lacks. The reason for this is two-fold. Firstly, second-hand freight wagons find a new home rather quickly according to DVB Bank (Metz & Radstake, 2013). Demand is strong and stable in a relatively small second-hand market resulting in stable prices. Secondly, DVB Bank identifies that even during the economic crisis of 2008 sufficient funds were available for investments in both the passenger and freight segment. As a result, there have not been many reasons to lower prices to stimulate demand.

When expanding Model 1 with multiple metric technical variables the effects of multicollinearity influence the results. An alternative model is introduced with Model 3 that creates parsimony by including only the strongest relationships through the Stepwise function. Instead of *Capacity general*, the model includes *Number of axles* and *Tare weight*. Later, it will become apparent this is not the best solution. The signs of the resulting coefficients seem unexpected at first, but can be explained. In general, wagons with a high tare weight are simply larger and thus more expensive. The sign of the relation between *Number of axles* and *Value* is influenced by the small difference in value between four- and six-axle wagons and by a number of high-value two- and four-axle wagons in the dataset.

Further expanding to Model 4 to research the effect of bogie types shows that *Number of axles* becomes not significant. The signs of the coefficients remain negative too, but a significant difference between wagons equipped with Y25 bogies or bogies from other design families and their two-axle counterparts remains. The relation between *Number of axles* and the presence of bogies at four axles or more is of influence here, so *Number of axles* is excluded in Model 5.

Model 5 shows no significant difference in value for different brake types. The presence of an Oerlikon brake system has a small negative effect on the value of a wagon, but its significance is discussable as it is almost significant at the 0.05 level. No clear difference is found between wagons equipped with a Knorr KE braking system and wagons with systems other than Knorr KE or Oerlikon.

Table 62: Freight wagons - Results - Pt. 2

Model	**6**		**7**		**8**		**9**		**10**	
Metric	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**	**β**	**Sig.**
Age	-.456	.000	-.518	.000	-.458	.000	-.241	.000	-.349	.000
Index freight market	---	---	---	---	---	---	---	---	---	---
Capacity general	---	---	---	---	---	---	.987	.000	.303	.000
Number of axles	---	---	---	---	---	---	-.976	.000	---	---
Speed loaded	---	---	---	---	---	---	---	---	---	---
Speed unloaded	---	---	---	---	---	---	---	---	---	---
Tare weight	.520	.000	.528	.000	.317	.000	.401	.000	---	---
Axle diameter	---	---	---	---	---	---	.201	.000	.282	.000
Non-metric										
Bogie family Y25	-.322	.000	-.247	.004	-.103	.246	---	---	---	---
Bogie family other	-.156	.022	-.127	.063	-.054	.398	---	---	---	---
Brake family Oerlikon	---	---	---	---	---	---	---	---	---	---
Brake family other	---	---	---	---	---	---	.096	.020	---	---
No revision	-.136	.054	-.156	.027	-.150	.020	-.139	.004	-.192	.000
Manufacturer Eastern Europe			-.170	.056	-.034	.694	---	---	---	---
Sector liquid bulk					.770	.443	---	---	---	---
Sector break-bulk					.540	.591	---	---	.119	.009
Sector intermodal					-.150	.881	---	---	---	---
Sector coils/plates					.209	.790	---	---	---	---
Sector cars					.365	.000	.660	.000	.694	.000
N	98		98		98		98		98	
Adj. R^2	64.6%		65.6%		73.2%		85.5%		81.2%	

When researching the effects of whether a wagon is in a valid maintenance regime (Model 6), an expected negative relation with value is found. Almost significant at the 0.05 level, it indicates that wagons requiring (heavy) maintenance are indeed sold at lower prices than those in a valid regime. This is observed in practice where a buyer pays a lower price when having to invest in an overhaul. Models 7 and 8 show that the data does not support differences in value between rolling stock built by Western or Eastern European manufacturers. The inclusion of sectors substantially raises the Adjusted R^2 to well above 70%.

Model 9 uses the Stepwise approach to see if the software can create a better parsimonious model. This approach is also aimed at taking away concerns about the high amount of multicollinearity during the more intuitive and theory-based approach used for previous models. It includes a combination of metric and non-metric variables. Even though this approach increases the value of the Adjusted R^2 to 85.5%, it raises concerns about multicollinearity between $Cap_{general}$ and No_{axle}. Both have a very strong relationship with *Value* and are highly significant. Multicollinearity statistics confirm previous concerns with very high values of 18,615 for $Cap_{general}$ and 21,652 for No_{axle}. Therefore, No_{axle} is excluded in Model 10.

The results of Model 10 present a parsimonious model with an Adjusted R^2 of 81.2%. With six variables, the Adjusted R^2 is lower than for Model 9, but multicollinearity is eliminated. A strong negative relationship between *Age* and *Value* is established, as well as a positive relation between $Cap_{general}$ and *Value*. Wagons with larger axle diameters are valued higher than those with smaller axle diameters and wagons not in a valid maintenance regime are valued lower than those that are. Lastly, differences between sectors appear to exist. Break-bulk wagons are valued slightly higher compared to other wagons and car transporters are valued substantially higher.

Appendix A8: Collinearity statistics

This appendix presents the collinearity statistics for the different models researched in Chapter 4. VIF values higher than 4 are marked in bold and indicate possible multicollinearity. Values between 4 and 5 have been regarded as reasonably acceptable, but suspicious.

A8.1 Locomotives

Table 63 lists the collinearity statistics for Models 1-6, Table 64 for Models 7-10.

Table 63: Collinearity statistics - Locomotives - Pt.1

Model	**1**		**2**		**3**		**4**		**5**		**6**	
Metric	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**
Age	.550	1.818	.703	1.412	.703	1.423	.700	1.428	.408	2.449	.359	2.532
Index passenger market	.580	1.725	---	---	---	---	---	---	---	---	---	---
Power rating primary	.830	1.205	.368	2.715	.315	3.173	.363	2.757	.354	2.825	.348	2.870
Speed			.309	3.235	.305	3.284	.307	3.261	.305	3.280	.304	3.286
Number of countries					.567	1.763	---	---	---	---	---	---
Non-metric												
ETCS L1							.969	1.032	---	---	---	---
ETCS L2							.940	1.063	.942	1.061	.942	1.061
No revision									.482	2.076	.472	2.117
Manufacturer Eastern Europe											.954	1.048

Table 64: Collinearity statistics - Locomotives - Pt.2

Model	**7**		**8**		**9**		**10**	
Metric	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**
Age	.394	2.539	.362	2.760	.659	1.517	.642	1.558
Index passenger market	---	---	---	---	---	---	---	---
Power rating primary	**.166**	**6.027**	.344	2.907	.357	2.801	.352	2.844
Speed	.304	3.293	**.212**	**4.714**	**.222**	**4.510**	**.215**	**4.657**
Number of countries	---	---	---	---	---	---	---	---
Gauge	---	---	---	---	---	---	.928	1.078
Non-metric								
ETCS L1	---	---	---	---	---	---	---	---
ETCS L2	.938	1.066	.941	1.063	.942	1.062	.935	1.070
No revision	.462	2.164	.454	2.203	---	---	---	---
Manufacturer Eastern Europe	.917	1.090	.928	1.077	.938	1.066	.938	1.066
Electric propulsion	.271	3.689	---	---	---	---	---	---
Sector shunter	---	---	.392	2.548	.408	2.448	.400	2.499
Interaction electric propulsion and sector					---	---	---	---

A8.2 Freight wagons

Table 65 lists the collinearity statistics for Models 1-5, Table 66 for Models 6-10.

Table 65: Collinearity statistics - Freight wagons - Pt.1

Model	**1**		**2**		**3**		**4**		**5**	
Metric	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**
Age	.591	1.691	.378	2.644	.675	1.481	.658	1.520	.642	1.558
Index freight market	.992	1.008	.932	1.073	---	---	---	---	---	---
Capacity general	.595	1.681	.055	**18.042**	---	---	---	---	---	---
Number of axles			.045	**22.215**	.297	3.364	.197	5.088	---	---
Speed loaded			.759	1.318	---	---	---	---	---	---
Speed unloaded			.510	1.961	---	---	---	---	---	---
Tare weight			.231	**4.338**	.301	3.319	.288	3.472	.572	1.749
Axle diameter			.752	1.330	---	---	---	---	---	---
Non-metric										
Bogie family Y25							.439	2.280	.652	1.534
Bogie family other							.703	1.423	.791	1.264
Brake family Oerlikon									.858	1.166
Brake family other									.934	1.071

Table 66: Collinearity statistics - Freight wagons - Pt.2

Model	**6**		**7**		**8**		**9**		**10**	
Metric	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**	**Tol.**	**VIF**
Age	.556	1.797	.481	2.080	3.99	2.506	.405	2.471	.475	2.107
Index freight market	---	---	---	---	---	---	---	---	---	---
Capacity general	---	---	---	---	---	---	**.054**	**18.615**	.545	1.834
Number of axles	---	---	---	---	---	---	**.046**	**21.652**	---	---
Speed loaded	---	---	---	---	---	---	---	---	---	---
Speed unloaded	---	---	---	---	---	---	---	---	---	---
Tare weight	.589	1.699	.587	1.704	.404	2.474	**.207**	**4.829**	---	---
Axle diameter	---	---	---	---	---	---	.589	1.698	.672	1.487
Non-metric										
Bogie family Y25	.656	1.525	.514	1.945	.354	2.821	---	---	---	---
Bogie family other	.810	1.234	.771	1.297	.686	1.459	---	---	---	---
Brake family Oerlikon	---	---	---	---	---	---	---	---	---	---
Brake family other	---	---	---	---	---	---	.921	1.085	---	---
No revision	.747	1.338	.731	1.368	.690	1.449	.693	1.443	.732	1.367
Manufacturer Eastern Europe			.459	2.180	.373	2.680	---	---	---	---
Sector liquid bulk					.838	1.194	---	---	---	---
Sector break-bulk					.653	1.532	---	---	.976	1.025
Sector intermodal					.808	1.237	---	---	---	---
Sector coils/plates					.790	1.267	---	---	---	---
Sector cars					.567	1.763	.505	1.979	.651	.1537

Appendix A9: Full results linear models

This appendix lists the detailed statistical results for the final locomotive and freight wagon models.

A9.1 Locomotives

Table 67: Model summary - Locomotives

R	R^2	Adjusted R^2	Std. Error of the Estimate
.918	.843	.833	600,958

Table 68: ANOVA - Locomotives

	Sum of squares	df	Mean Square	F	Sig.
Regression	2.321E+14	7	3.316E+13	91.817	.000
Residual	4.334E+13	120	3.612E+11		
Total	2.755E+14	127			

Table 69: Coefficients - Locomotives

Model	10						
	Unstandardized coefficients		**Stand. coefficients**			**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Tolerance**	**VIF**
Constant	-5,195,619	1,899,907		-2.735	.007		
Age (year)	-32,624	2,976	-.495	-10.962	.000	.642	1.558
Power rating primary (kW)	204	42	.296	4.853	.000	.352	2.844
Speed (km/h)	10,745	2,492	.337	4.312	.000	.215	4.657
ETCS L2	775,831	259,918	.112	2.985	.003	.935	1.070
Gauge (mm)	4,009	1,263	.119	3.176	.002	.928	1.078
Manufacturer Eastern Europe	-638,254	136,335	-.175	-4.682	.000	.938	1.066
Sector shunter	533,215	198,221	.154	2.690	.008	.400	2.499

Table 70: Residuals Statistics - Locomotives

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-781,341	4,789,815	1,894,988	1,351,923	128
Residual	-1,137,494	1,375,727	.000	584,161	128
Std. Predicted Value	-1,980	2.141	.000	1.000	128
Std. Residual	-1.893	2.289	.000	.972	128

A9.2 Freight wagons

Table 71: Model summary - Freight wagons

R	R^2	Adjusted R^2	Std. Error of the Estimate
.907	.823	.812	20,115

Table 72: ANOVA - Freight wagons

	Sum of squares	df	Mean Square	F	Sig.
Regression	1.715E+11	6	2.858E+10	70.646	.000
Residual	3.682E+10	91	404,598,899.8		
Total	2.083E+11	97			

Table 73: Coefficients - Freight wagons

Model	**10**						
	Unstandardized coefficients		**Stand. coefficients**			**Collinearity statistics**	
	B	**Std. Error**	**β**	**t**	**Sig.**	**Tolerance**	**VIF**
Constant	-469,013	94,903		-4.942	.000		
Age (year)	-908	166	-.349	-5.462	.000	.475	2.107
Capacity general (tonne)	729	144	.303	5.078	.000	.545	1.834
Axle diameter (mm)	541	103	.282	5.247	.000	.672	1.487
No revision	-21,268	5,693	-.192	-3.736	.000	.732	1.367
Sector break-bulk	14,824	5,565	.119	2.664	.009	.976	1.025
Sector cars	226,377	17,815	.694	12.707	.000	.651	1.537

Table 74: Residuals Statistics - Freight wagons

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-23,018	292,789	57,360	42,048	98
Residual	-52,251	68,230	.000	19,483	98
Std. Predicted Value	-1.912	5.599	.000	1.000	98
Std. Residual	-2.598	3.392	.000	.969	98

APPENDIX A10: LINEAR MODEL EVALUATION AND VALIDATION OF RESULTS

This chapter provides a more in-depth evaluation of the results in Chapter 4. First, explanatory power is assessed, followed by the generalizability of the results. Subsequently, evaluation of the found relationships takes place by means of visual validation. Then, a number of diagnostic techniques are applied to see how well the assumptions for multiple regression hold, to provide more certain results with respect to the presence of linearity.

A10.1 EVALUATION OF THE EXPLANATORY POWER

The power can be seen as the chance to not falsely conclude that there is no relationship between variables, when in reality there is. The used significance level is 0.05 and the desired power is 0.80.

A10.1.1 LOCOMOTIVES

With 128 cases and 7 independent variables, the final locomotive model returns an Adjusted R^2 of 83.3% and a R^2 value of 84.3%. At a sample size of 100 cases and a power of 0.80, the minimum R^2 value that can be detected statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. For a sample size of 250 cases, it lies between the 5% and 6%. As the minimum R^2 values are sufficiently low, explanatory power is sufficiently high.

A10.1.2 FREIGHT WAGONS

Estimated using 98 cases and 6 independent variables, the final freight wagon model returns an Adjusted R^2 of 81.2% and a R^2 value of 82.3%. For 100 cases and a power of 0.80, the minimum R^2 value that can be found statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. The minimum R^2 values that can be detected are sufficiently low and explanatory power sufficiently high.

A10.2 GENERALIZABILITY OF RESULTS

To safeguard generalizability of the outcomes, the ratio between the number of observations and independent variables should be sufficiently high. In general, the minimum ratio is 1:5, but a ratio of 15 to 20 cases per explanatory variable is preferred. When using the Stepwise estimation procedure, a ratio of 1:50 is desired. The following subsections show that increasing the significance level to 0.1 from 0.05, which causes effects to become statistically significant earlier and thus see more variables added, at a stabile number of cases would endanger generalizability of the outcomes.

A10.2.1 LOCOMOTIVES

The final locomotive model is estimated with 128 cases. The number of independent variables in the model is 7. This results in a ratio of 18.3 cases per independent variable in the model, which lies within the preferred range of 15 to 20. However, as the Stepwise procedure is used, further validation is required to ensure generalizability.

A10.2.2 FREIGHT WAGONS

For freight wagons, 98 cases are available. With 6 independent variables in the model, the ratio becomes 1:16.3, which falls within the preferred range. Here the Stepwise function is used too, but a ratio of 1:50 is not reached. The results are subjected to further validation.

A10.3 VISUAL EVALUATION AND GROUP DIFFERENCES

A basic assumption of multiple regression is the presence of linearity between the independent variables and the dependent variable. In this section, it is researched whether this assumption is violated or not (e.g. due to the dataset used) and to which extent multiple regression is a suitable method in this regard. Multiple regression has not been used in relation to rail vehicle valuation before. Checking for linearity, corrected for multiple explanatory variables, provides starting points for future quantitative research regarding the actual relationship between non-linear explanatory variables and rail vehicle value. This section contains the most eye-catching results. A more elaborate analysis is included in Appendix A11.

A10.3.1 LOCOMOTIVES

Firstly, the statistically significant variables found with the final locomotive model (Model 10, Section 4.2.2) are discussed:

- *Age*
- *Power rating primary*
- *Speed*
- *Gauge*
- *ETCS L2*
- *Manufacturer Eastern Europe*
- *Sector Shunter*

Overall, the assumption of linearity is met quite well and group differences are confirmed. However, for two variables this is less apparent than for the rest: *Age* and *Power rating primary*. The plot in Figure 22 reveals that linearity is not inappropriate, but may hint at a curvilinear relationship. Although straight-line deprecation is used in practice, it was established in Chapter 2 that curvilinear deprecation techniques have distinct advantages, as they cover:

- the effects of decreasing usefulness over time due to technological progress; and
- the effects of decreasing benefits through increased operational costs over time.

However, these effects may be captured in technical variables. Although no notion of operational costs is included in the model, this separation is considered important.

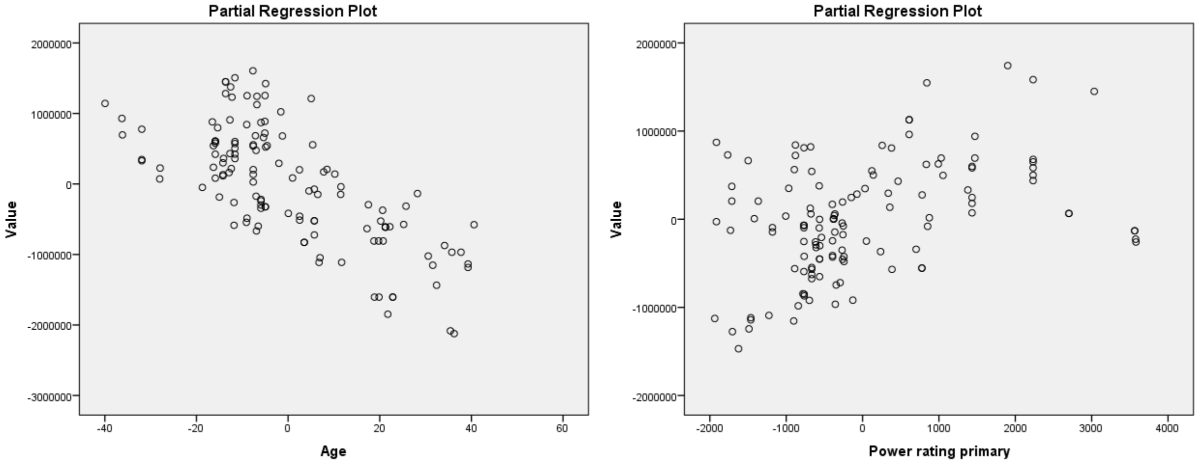


FIGURE 22: PARTIAL REGRESSION PLOT AGE AND VALUE (L) & POWER RATING PRIMARY AND VALUE (R)

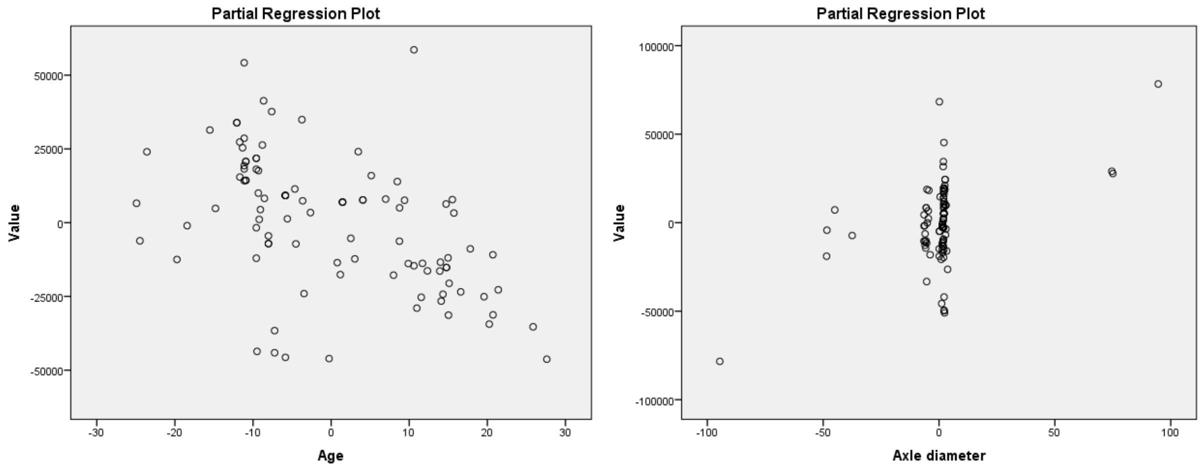
There is no doubt about a positive relationship between a locomotive's power rating and its value (Figure 22). The general shape of the cloud of points could indicate a curved increasing relationship, but this is not fully clear due to a lack of observations in the lowest power rating range. Similar to locomotives, linearity is not fully inappropriate, but also that the exact nature of the relation is doubtful.

A10.3.2 FREIGHT WAGONS

This section discusses the statistically significant variables found of the final freight wagon model (Model 10, Section 4.3.2):

- *Age*
- *Capacity general*
- *Axle diameter*
- *No revision*
- *Sector break-bulk*
- *Sector cars*

The suitability of linear estimation is more apparent for freight wagons than for locomotives. The relationship between *Age* and *Value* can be linked to use of linear depreciation profile in practice when looking at the concentrations of observations (Figure 23).


Partial Regression Plot

Partial Regression Plot

Figure 23: Partial regression plot Age and Value (l) & Axle diameter and Value (r)

At first, Figure 23 seems to reveal the failure of recognizing groups of axle diameters. Although standard diameters exist, the possible inclusion of diameters for worn axles requires this setup. That 920 mm axles are the standard is clearly visible. However, even with little data for wagons with non-standard axles, those with large axle diameters appear to be valued substantially higher than wagons with small diameters and a linear relation can be assumed.

A10.4 Normality of the prediction error term

After checking for linearity, it is checked if normality of the error term of the model is respected. This error term represents that part of the observed vehicle value that cannot be explained by the model. It includes differences as the result of the state of the vehicle, which is assumed to be in normal condition (e.g. no missing parts, good condition of paint layers, etc.), whether in a valid maintenance regime or not. Other aspects are the effects of the interaction between supply and demand, and the availability of spare parts and knowledge to keep the vehicle running. Normality of this error term is checked by assessing the normal probability plot of the standardized residuals.

A10.4.1 Locomotives

The normal probability plot of the standardized residuals for the locomotive model is visualized in Figure 24. The values are in line with the diagonal, so the normality assumption is met.

A10.4.2 Freight wagons

For the freight wagon model, the normal probability plot of the standardized residuals is presented in Figure 24. The assumption of normality is met here too.

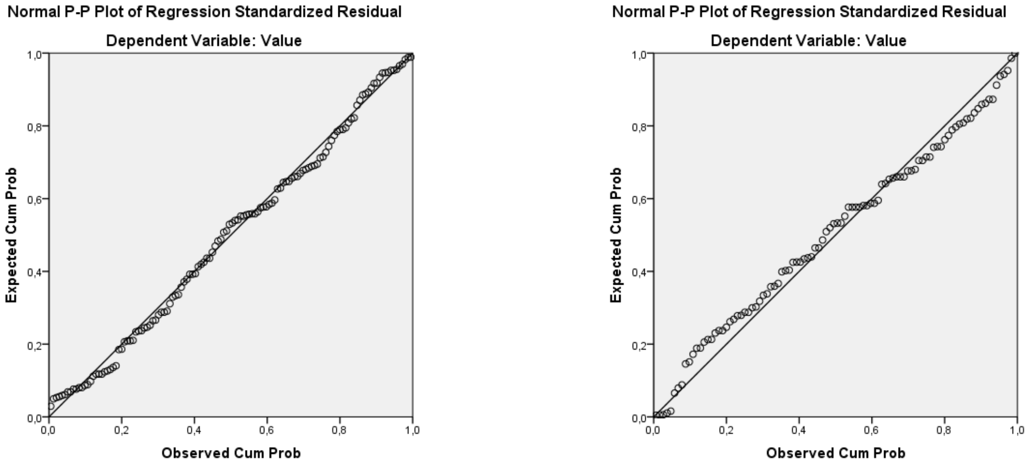


Figure 24: Normal probability plots standardized residuals for locomotives (l) & freight wagons (r)

A10.5 Linearity and homoscedasticity

By plotting the regression standardized residual against the regression standardized predictive value, it can be checked whether linearity and homoscedasticity exist. If the model is linear, no clear pattern is recognizable between the two. If homoscedasticity exists – so if, for every combination of values for all independent variables in the population, there is a normal distribution of the values of the dependent variable with constant variation – there is a good spread of points around the horizontal null line and thus no diverging or converging pattern.

This final check for linearity provides clarity if the assumption of linearity between the market value of locomotives and freight wagons and their respective explanatory factors is supported. If not, non-linearity exists. In that case, it is shown that for locomotive and freight wagon valuation non-linear techniques should be embraced.

A10.5.1 Locomotives

Figure 25 shows the standardized residual plotted against the standardized predictive value. Looking at the plot, the number of points above and under the horizontal null line is approximately even. However, especially on the right side (between 0 and 2 on the x-axis) it would be possible to give the presence of homoscedasticity the benefit of the doubt.This does not apply to the left side of the plot (between -2 and 0 on the x-axis).

The left part of the plot shows that, especially for lower valued locomotives, the assumption of linearity is not fully met and a curved relationship is indeed likely. Nevertheless, as visual evaluation has shown, linear representation is not fully inappropriate. However, this will have an effect on the confidence intervals and thus the predictive accuracy.

A10.5.2 Freight wagons

Figure 25 plots the standardized residual against the standardized predictive value. Despite a few outliers representing cases decided not to be deleted earlier, the values are spread around the horizontal null line quite well. However, the shape hints at slight heteroscedasticity despite the rectangular concentration of points between approximately -1 and 1 on the x-axis.

The general shape underlines that also for the market value of freight wagons non-linearity may exist, even though linear estimation of value is even more appropriate for this group of vehicles than for locomotives. This conclusion is in line with those drawn from visual evaluation of the individual relationships.

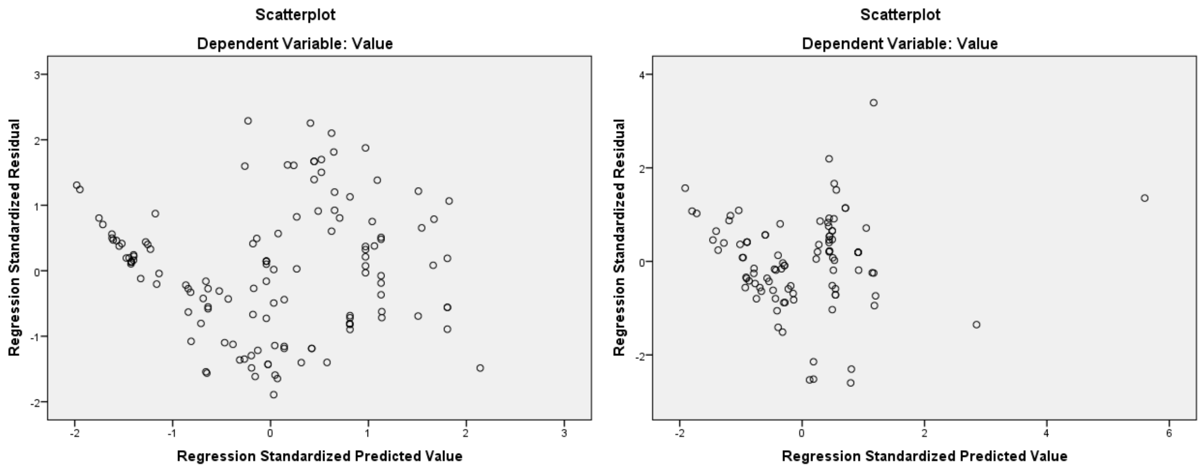


Figure 25: Standardized residuals plots for locomotives (L) and freight wagons (R)

A10.6 Significance of regression coefficients

To gain insight in coefficient significance, the standard errors of the coefficients and the 95% confidence intervals are established. The broader the intervals, the more uncertainty exists about the value of the found coefficients. The most important results are complemented with a visual representation. For the full visual results, the reader is referred to Appendix A11.

A10.6.1 Locomotives

Table 75 presents the coefficients of the locomotive model, the corresponding standard errors and the 95% confidence intervals. Notable are the sizeable standard errors for the *ETCS L2*, *Gauge* and *Sector shunter*, indicating that more expected variation in the estimated coefficients due to sampling error than for other variables.

Table 75: Confidence intervals - Locomotives

Variable	β	B	Std. error	Lower bound	Upper bound	Interval	Expected coefficient variation	
							t	Rank
Constant		-5,195,619	1,899,907	-8,957,302	-1,433,935	7,523,367	-2.735	High
Age (year)	-.495	-32,624	2,976	-38,516	-26,731	11,785	-10.962	Low
Power rating primary (kW)	.296	204	42	121	288	167	4.853	Med.
Speed (km/h)	.337	10,745	2,492	5,811	15,679	9,868	4.312	Med.
ETCS L2	.112	775,831	259,918	261,212	1,290,449	1,029,237	2.985	High
Gauge (mm)	.119	4,009	1,263	1510	6,509	4,999	3.176	High
Manufacturer Eastern Europe	-.175	-638,254	136,335	-908,188	-368,319	539,869	-4.682	Med.
Sector shunter	.154	533,215	198,221	140,751	925,680	784,929	2.690	High

As the difference between the upper and lower bound roughly equals roughly four times the standard error (±1.96*Std.Error), high standard errors indicate a high expected variation of the estimated coefficients due to sampling error. Most variation is found for the three previously mentioned variables, lowest for the coefficient of *Age*. None of the confidence intervals include zero, indicating that statistical significance was established. The matches the criterion to only include significant coefficients in the model.

The confidence interval for *Manufacturer Eastern Europe* (Figure 26) visualizes the variation in coefficient value due to asymmetry in the number of cases per manufacturer region. However, there is no doubt about the negative nature of the relationship.

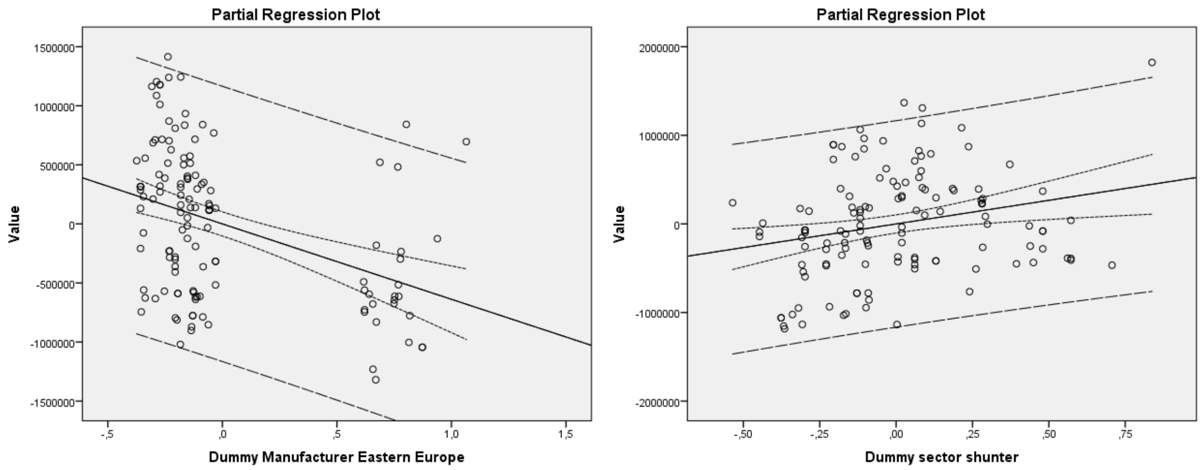


Figure 26: Confidence intervals Manufacturer Eastern Europe and Value (L) & Sector shunter and Value (R)

Figure 26**Fout! Verwijzingsbron niet gevonden.** visually confirms the high uncertainty in coefficient value for *Sector shunter*. The fitted regression line follows the highest concentration of cases quite well, but the nature of the relationship may vary between slightly positive and strongly positive.

A10.6.2 FREIGHT WAGONS

Table 76 lists the coefficients, the corresponding standard errors and the corresponding 95% confidence intervals of the freight wagon model. Most apparent is the large standard error for *Sector break-bulk* compared to the standard errors of the other variables.

Table 76: Confidence intervals - Freight wagons

VARIABLE	β	B	STD. ERROR	LOWER BOUND	UPPER BOUND	INTERVAL	EXPECTED COEFFICIENT VARIATION	
							t	RANK
Constant		-469,013	94,903	-657,527	-280,499	377,028	-4.942	Med.
Age (year)	-.349	-908	166	-1,238	-578	660	-5.462	Med.
Capacity general (tonne)	.303	729	144	444	1,014	570	5.078	Med.
Axle diameter (mm)	.282	541	103	336	746	409	5.247	Med.
No revision	-.192	-21,268	5,693	-32,577	-9,959	22,617	-3.736	Med.
Sector break-bulk	.119	14,824	5,565	3,770	25,879	22,110	2.664	High
Sector cars	.694	226,377	17,815	190,990	261,765	70,776	12.707	Low

As the difference between the upper and lower bound equals ±1.96*Std.Error, high standard errors indicate a high variation in the estimated coefficients due to sampling error can be expected. Overall, the expected variation in coefficients due to sampling error is lower for the freight wagon model than for the locomotive model. None of the confidence intervals include zero, so statistical significance is established.

Visually, the found confidence intervals largely confirm these outcomes. For *axle diameter*, it clearly shows that zero does not lie within the confidence interval (Figure 27), confirming the statistical significance of the coefficient. However, there is relatively high variation in the coefficient value due to low for low and high axle diameters.

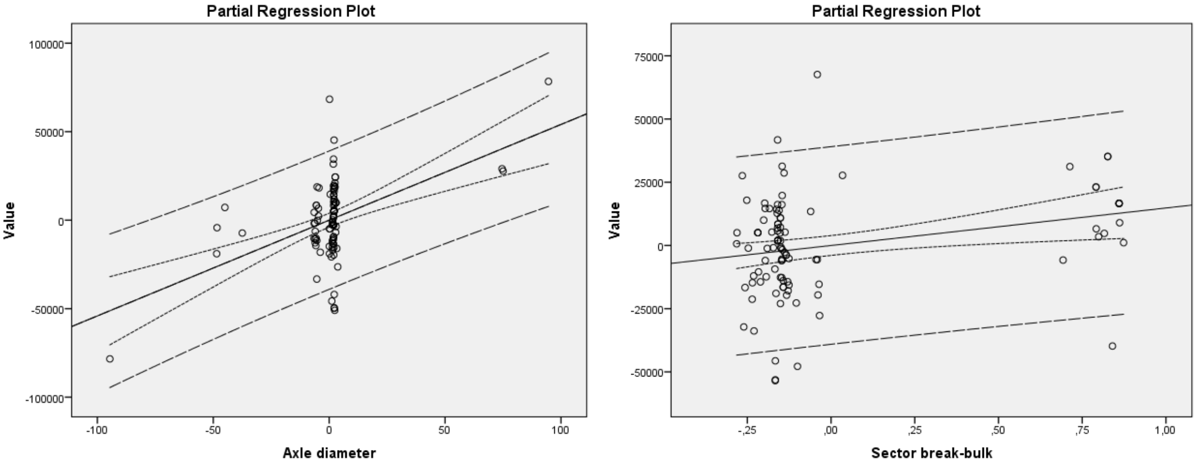


Figure 27: Confidence intervals Axle diameter and Value (l) & Sector break-bulk and Value (r)

Visualizing this for *Sector break-bulk*, confirms that zero is not part of the confidence interval, but the confidence bands do leave room for a coefficient value of nearly zero. This means that if more break-bulk wagons with relatively low values are observed, the presence of the relationship between *Sector break-bulk* and *Value* may become troublesome.

Appendix A11: Visual evaluation and group differences

This appendix provides an in-depth visual assessment of linearity – one of the basic assumptions behind multiple regression – and group differences. It is researched whether this assumption is violated for two reasons. Firstly, the validity of the model depends on correctly estimated relations. Secondly, multiple regression has not been used in rail vehicle valuation before. So, identifying possible non-linearity provides insight into how suitable multiple regression and provides starting points for future research into rail value determinants.

A11.1 Locomotives

Age

The partial regression plot for *Age* and *Value* (Figure 28) shows the effect of *Age* corrected for the presence of other independent variables in the model. Therefore, the values cannot be linked directly to the actual values in the dataset.

There is room for two interpretations, as one can recognize both a linear and a slightly decreasing curved relationship. In Chapter 2, three different time-based depreciation methods used in accounting for book value estimation are presented (Section 2.4): Straight Line, Declining Balance Method and Sum of the Years' Digits. Although uncertainty exists about the recommended method, the Straight Line Method is generally used in practice. Naturally, the book value differs from the fair market value as it still lacks the influence of supply and demand. Whilst time-based depreciation techniques only consider age, other explanatory variables are taken into account in this thesis.

On the other hand, one could see non-linearity between *Age* and *Value*. This would in line with the assumptions of the Declining Balance Method and the Sum of the Years' Digits Method that depreciation charges decrease over time for assets which usefulness is subject to technological progress. However, effects of decreasing usefulness on market value may be captured in (technical) variables and should not be of influence on value through age. Furthermore, rail vehicles tend to have long useful lifespans that can cover forty years or more, which does not support the previous assumption regarding decreasing usefulness.

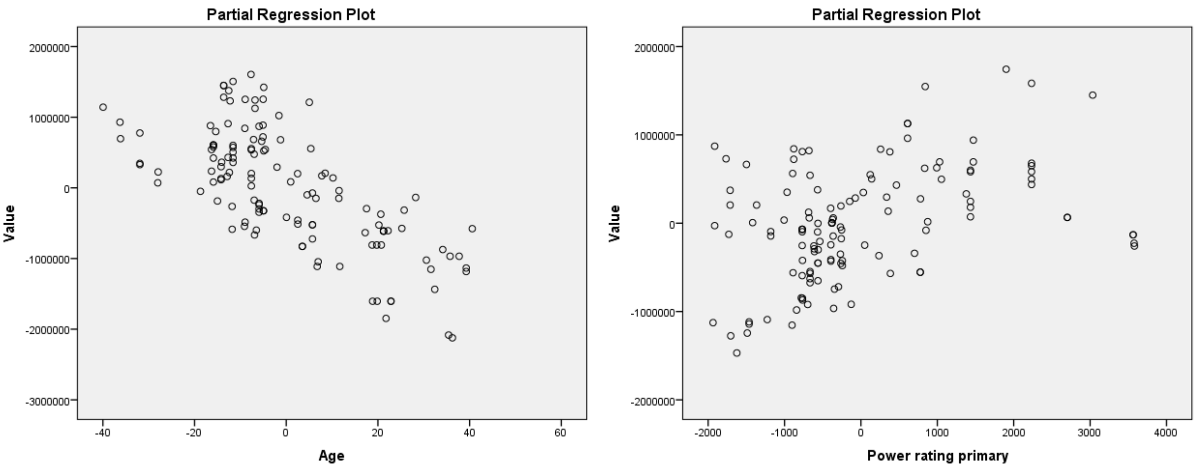


Figure 28: Partial regression plots Age and Value (l) & Power rating primary and Value (r)

Power rating primary

Despite the small blank space in the middle-left region of the plot (Figure 28), the majority of the plotted values indicates a positive linear relationship between a locomotive's power rating and its value. However, the general shape of the cloud of points could indicate a curved increasing relationship too. The blank space indicates a lack of observations in the lowest power rating range.

Speed
The influence of speed on value shows a spread pattern in the partial regression plot in Figure 29. The scatterplot moves slightly upward with a high concentration of points in the centre of the cloud. On both sides of the horizontal and vertical null-lines, a similar amount of points can be recognized indicating a good spread in observations.

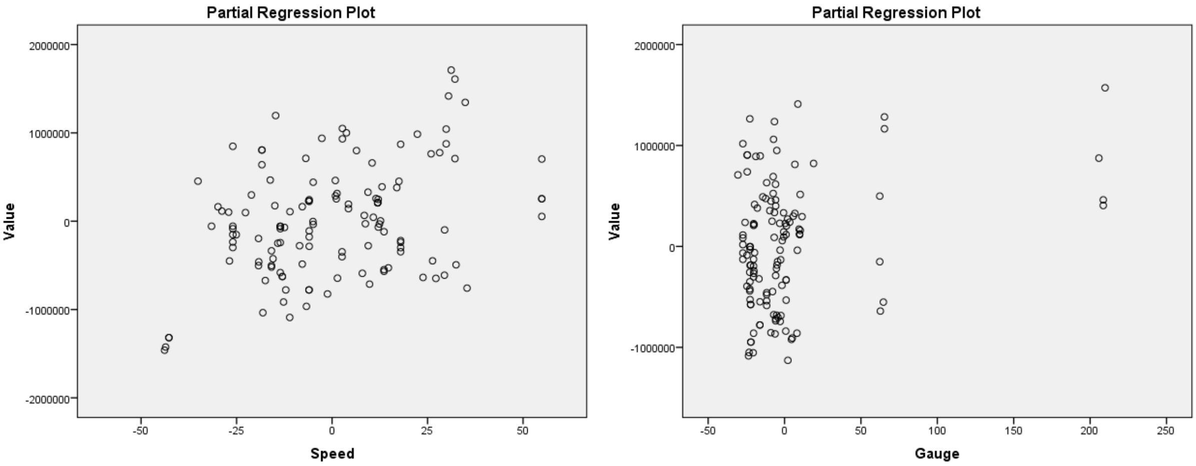


FIGURE 29: PARTIAL REGRESSION PLOTS SPEED AND VALUE (L) & GAUGE AND VALUE (R)

Gauge
At first sight, the partial regression plot from Figure 29 could indicate a failure to recognize groups of gauges, as one can distinguish three main groups, namely narrow, standard and broad gauge. In this case, we can see the differences between 1435 mm standard, 1520 mm broad and 1668 mm broad gauge. The small amount of data on broad gauge vehicles also questions the accuracy of the found relationship. Considering the large number of gauges that exist (e.g. 1000, 1067, 1435, 1520, 1524, 1600, 1668 and 1676 mm), the variable has been assumed to be of a metric nature.

The positive relation found is as expected, showing an increasing relationship even with the small amount of points on the right. Because they represent true vehicle values, it is difficult to mark them as outliers. Compared with practice, a positive relationship towards broad gauge locomotives is realistic, as broad gauge locomotives are generally stronger and heavier. The spread for the 1520 mm vehicles does not indicate a true difference, because the 1520 mm market is a large market too. While standard gauge is most commonly used worldwide, 1520 mm broad gauge comes second as it is used in the CIS-area and the Baltics. The 1668 mm Iberian gauge is slightly smaller and more specific, but synergy with Indian gauge (1676 mm) has seen second-hand transactions from Spain and Portugal to Chile and Argentina where 1676 mm is used too.

ETCS L2
On-board ETCS Level 2 causes a significant value difference. Figure 30 shows this difference between non-ETCS L2 vehicles (0) and vehicles with ETCS L2 (1). W. Radstake of DVB Bank SE (personal communication, February 2, 2016) indicates that the costs to install ETCS are circa €350,000, if the type is already approved with the system. Accordingly, new vehicles not yet approved with the system, are more expensive. Mitsui Rail Capital Europe (2011) indicates that values between €550,000 and €740,000 can occur when a vehicle has not yet been approved with the system and prototyping is required. It mentions a value of €650,000 as most representative in this case.

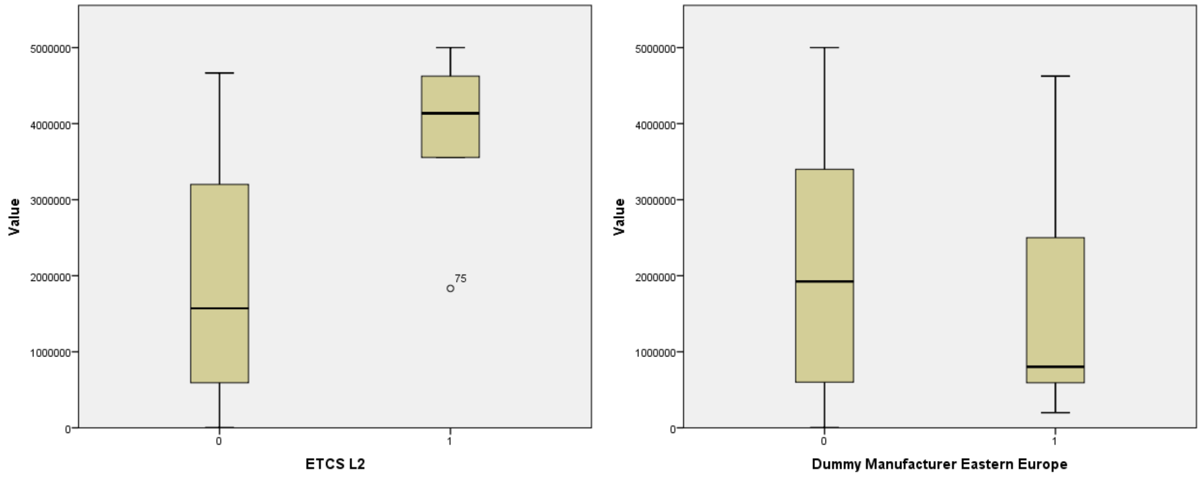


FIGURE 30: BOXPLOTS ETCS L2 AND VALUE (L) & MANUFACTURER EASTERN EUROPE AND VALUE (R)

Looking at the boxplot, the median and the lower bound value of a vehicle with ETCS L2 on board approximately approach the value range for ETCS installations mentioned above. The values approaching the upper bound of the box may be linked to more expensive multisystem locomotives where ETCS hardware is not the only driver of a higher price.

Manufacturer Eastern Europe

Also of interest is whether locomotives built by Eastern European manufacturers (1) are to be valued differently than vehicles produced in Western Europe (0). The regression analysis confirms this and shows a significant difference. The boxplot in Figure 30 shows no clear difference between the lower bounds of the boxes, but the upper bounds and medians do differ, indicating a difference in valuation. The bandwidth of both boxes is similarly high, indicating that also for vehicles from Eastern Europe exceptional values exist that vary strongly around the median.

Sector shunter

The boxplot in Figure 31 shows a large difference in value between mainline (0) and shunting locomotives (1) in the dataset, but also two particularities. Firstly, there are two outliers concerning modern shunters with exceptionally high values. Secondly, the relatively large number of old and low number of new shunters cause a low median value and a small box size. Despite these particularities, the difference in value between mainline locomotives and shunter corresponds with practice.

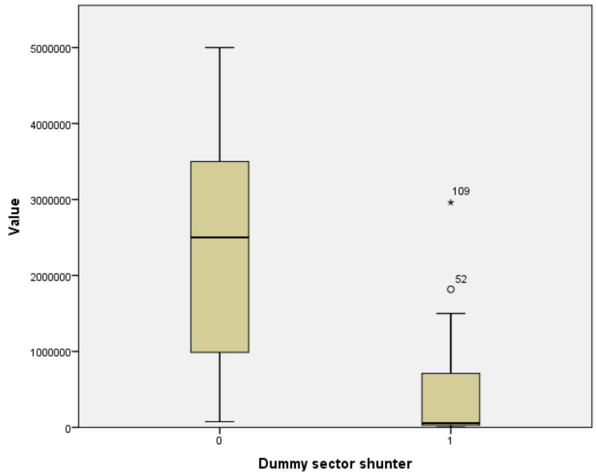


FIGURE 31: BOXPLOT SECTOR SHUNTER AND VALUE

A11.2 Freight wagons

This section discusses the significant variables of the final freight model (Model 10, Section 4.3.2).

Age

The direction of the relationship between Age and Value is negative as expected (Figure 32). Linearity is more apparent here than for locomotives. The scatterplot contains two clusters with a high concentration of points. A medium-high amount of relatively closely located points is found in the middle. A linear relation corresponds with the relationship assumed in practice for book value calculations. As established in Section 2.4.1, the Straight Line Method is generally used for this by the rail industry. Although not depicting book value – the effects of supply and demand, and other variables in the model are present here – the dataset supports the use of linear techniques to determine the effect of age on freight wagon value.

Capacity general

A linear relationship between the capacity and the value of a freight wagon has been assumed. The correlations and multiple regression analysis support a positive linear relation between *Capacity* and *Value*. Figure 32 reveals an upward slope, slightly clouded by the many observations in the centre. The outlying points on the left are not seen as true outliers as they are well positioned in line with the more numerous points to the right.

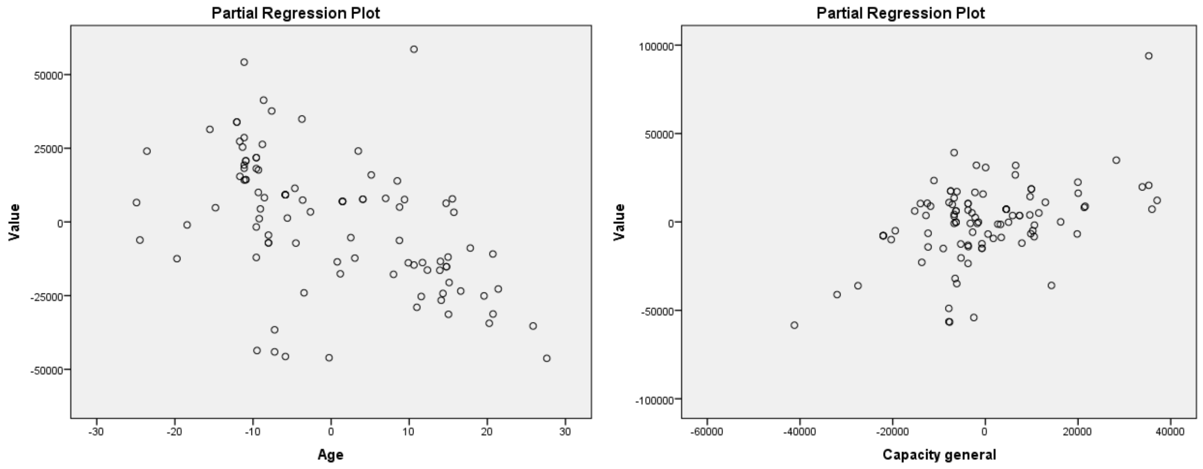


Figure 32: Partial regression plots Age and Value (l) & Capacity & Value (r)

Axle diameter

Figure 33 shows something similar as witnessed for *Gauge*. At first, one could say that there has been the failure to recognize groups of axle diameters, as 920 mm is the most common diameter. However, this choice has been made beforehand to enable the inclusion of second-hand wagons with worn axles that have not yet reached there minimum diameter. Even with little data for wagons with non-standard axle diameters, something interesting can be deduced. Although future research should cover a larger number of wagons with non-standard axle diameters, wagons with higher axle diameters appear to be valued substantially higher than those with smaller diameters.

No revision

This variable has an important influence on the price of (second-hand) freight wagons. When freight wagons are not in a valid revision regime (1), the value of vehicles is significantly lower than if they are (0). This can be deduced from the large difference in the position of the boxes relative to each other in Figure 33. The lower part of the bandwidth for vehicles sold in a valid maintenance regime only partly overlaps with the box for wagons not in a valid regime.

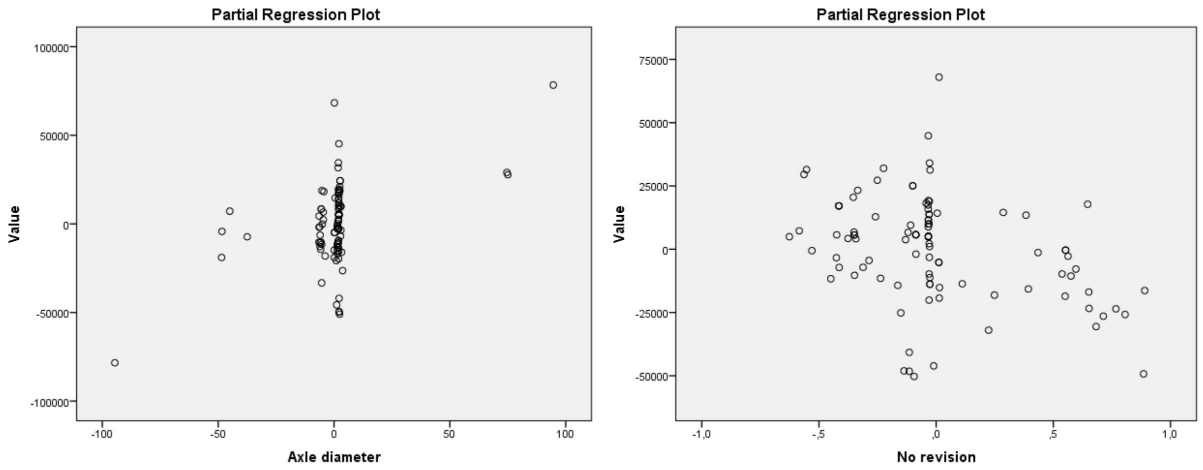


FIGURE 33: PARTIAL REGRESSION PLOTS AXLE DIAMETER AND VALUE (L) & NO REVISION AND VALUE (R)

Sectors

Two sectors have showed significant differences with other sectors: *Sector Break-bulk* and *Sector Cars*. The sectors that did not show to be of significant influence are dry bulk, liquid bulk, intermodal and coils/plates. Figure 34 shows that the bandwidth of wagons belonging to the sector break-bulk (1) is considerably smaller than for other wagons (0). As 50% of the observations are represented by the box, it shows that the variety in values is quite small for break-bulk wagons. Especially in the higher regions, this makes a difference. Note that circa 25% of the cases for non-break-bulk wagons varies between €100,000 and €200,000.

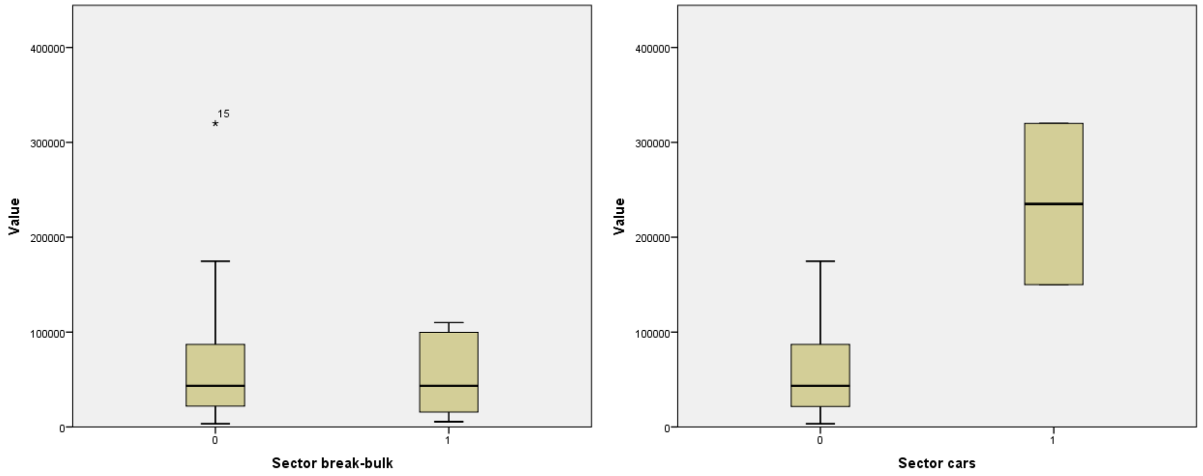


FIGURE 34: BOXPLOTS SECTOR BREAK-BULK AND VALUE (L) & SECTOR CARS AND VALUE (R)

A second boxplot, representing the differences in value between car transporters (1) and wagons belonging to different sectors (0), shows a considerable difference between the two groups. The bandwidth of other wagons only just overlaps with the box for car transporters, but the boxes themselves do not overlap. Although the number of observations for car transporters is much smaller, the values are representative. Therefore, it is still possible to consider the difference between the groups valid.

A difference between the groups becomes clear in Figure 35. This boxplot shows the six sectors and the difference in value ranges between car transporters and other freight wagons. Only the bandwidth of intermodal wagons manages to reach the lower bound of the box for car transporters.

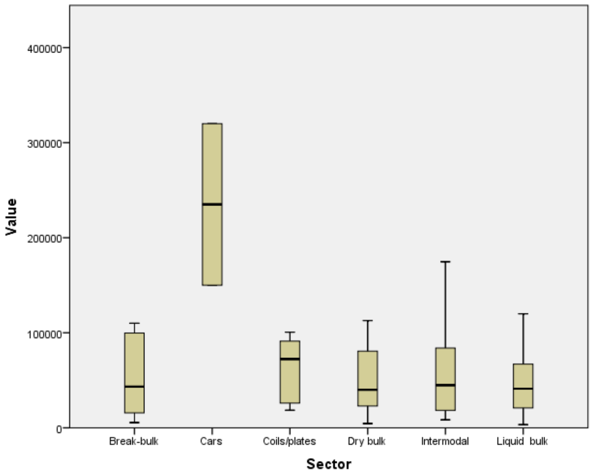


FIGURE 35: BOXPLOT SECTORS AND VALUE

Appendix A12: Confidence intervals

This appendix presents a visual presentation of the 95% confidence (diverging dashed lines) and prediction intervals (parallel dashed lines) of the model coefficients. The smaller the confidence interval, the less expected variation of the estimated coefficients. If the confidence interval does not include zero, the coefficient may be considered statistically significant.

A12.1 Locomotives

Figure 36 shows the partial regression plot for *Age* and *Value*. The confidence bands are satisfactory and confirm statistical significance.

The confidence interval for *Power rating primary* confirm statistical significance, as they do not include zero.

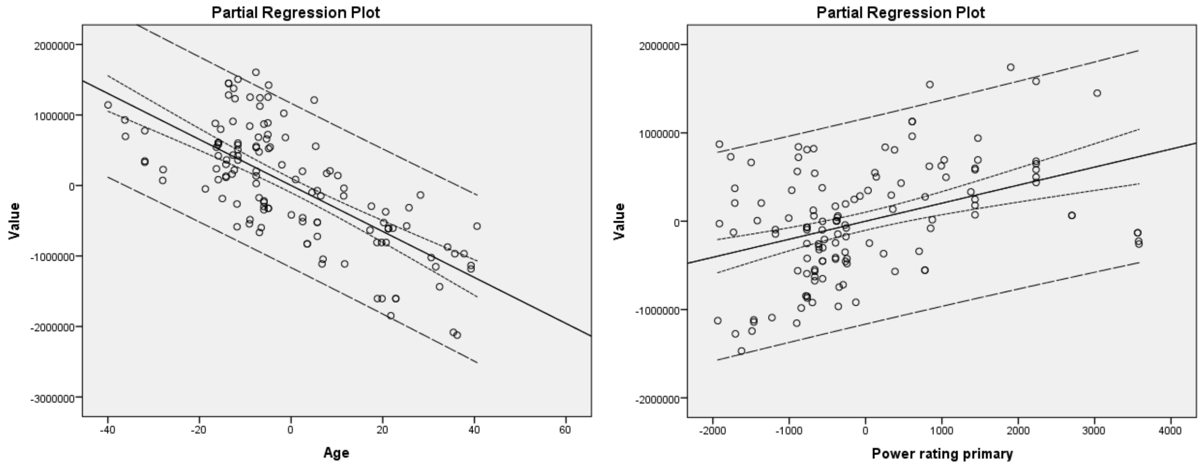


Figure 36: Confidence intervals Age and Value (l) & Power rating primary and Value (r)

Figure 37 presents the confidence interval for *Speed*, which confirm zero lies not within the upper and lower bound. Therefore, statistical significance of the coefficient is confirmed.

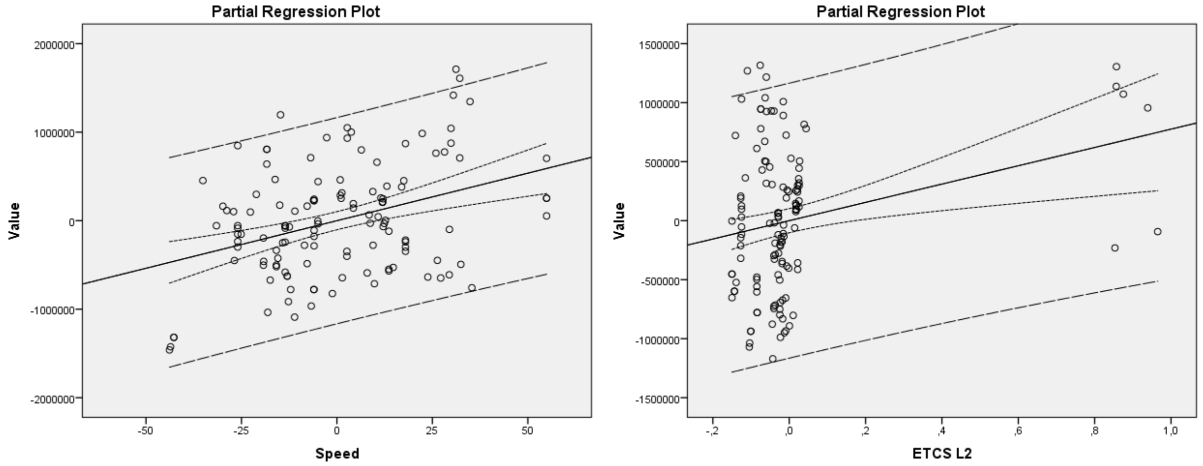


Figure 37: Confidence intervals Speed and Value (l) & ETCS L2 and Value (r)

The confidence interval for *ETCS L2* and *Value* confirms the statistical significance of the coefficient. The large amount of observations for vehicles without ETCS L2, mainly because the system was still upcoming in the period covered by the sample, creates a broad interval. In practice, the costs of installing ETCS in vehicle types not yet certified with the system vary considerably, as indicated by Mitsui Rail Capital Europe (2011). Despite the larger confidence intervals, costs exceeding €700,000 have occurred in practice. Additional observations are likely to decrease the width of the confidence bands in this region and further confirm statistical significance.

Something similar occurs for *Gauge* in Figure 38. The increasing relationship is as expected, but the small number of observations for broad gauge locomotives greatly influences the width of the confidence bands. Statistical significance, however, is confirmed.

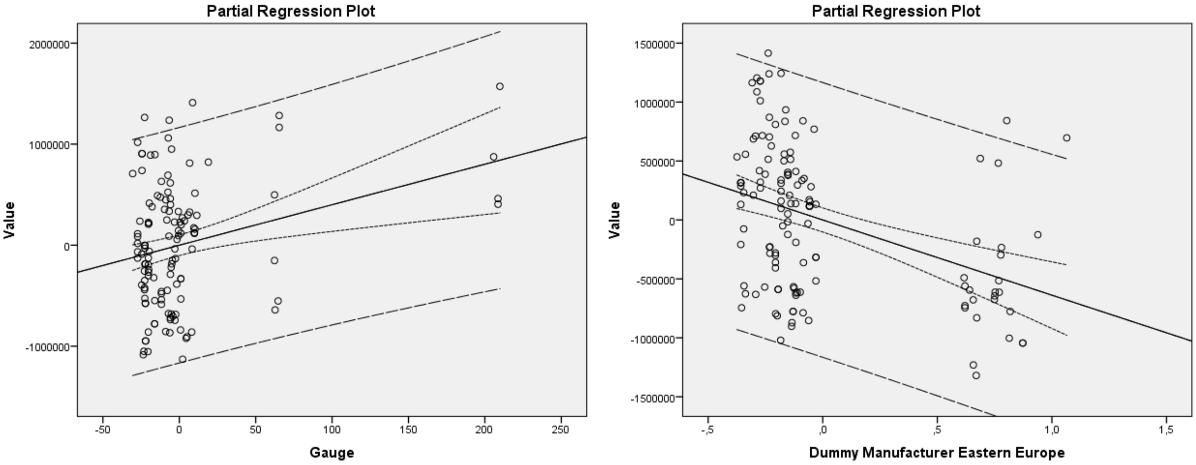


FIGURE 38: CONFIDENCE INTERVALS GAUGE AND VALUE (L) & MANUFACTURER EASTERN EUROPE AND VALUE (R)

For *Manufacturer Eastern Europe* (Figure 38), the expected variation of the estimated coefficient is much lower. As zero does not lie within the confidence interval, statistical significance is confirmed.

Lastly, the confidence intervals for *Sector shunter* are visualized in Figure 39. The confidence bands are satisfactory small and exclude a coefficient with the value zero, establishing statistical significance of the coefficient.

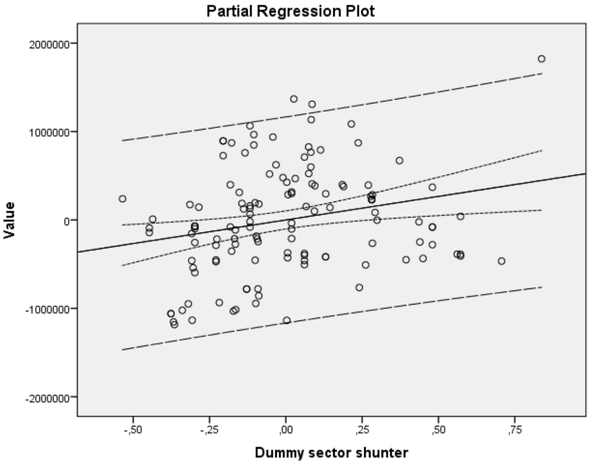


FIGURE 39: CONFIDENCE INTERVALS SECTOR SHUNTER AND VALUE - LOCOMOTIVES

A12.2 FREIGHT WAGONS

Figure 40 visualizes the linear relationship between *Age* and *Value*. The confidence bands show no extreme diversions from the regression line, indicating the expected variation of the coefficient due to sampling error is rather low. Furthermore, we can be quite certain that the coefficient of the found relationship does not equal zero.

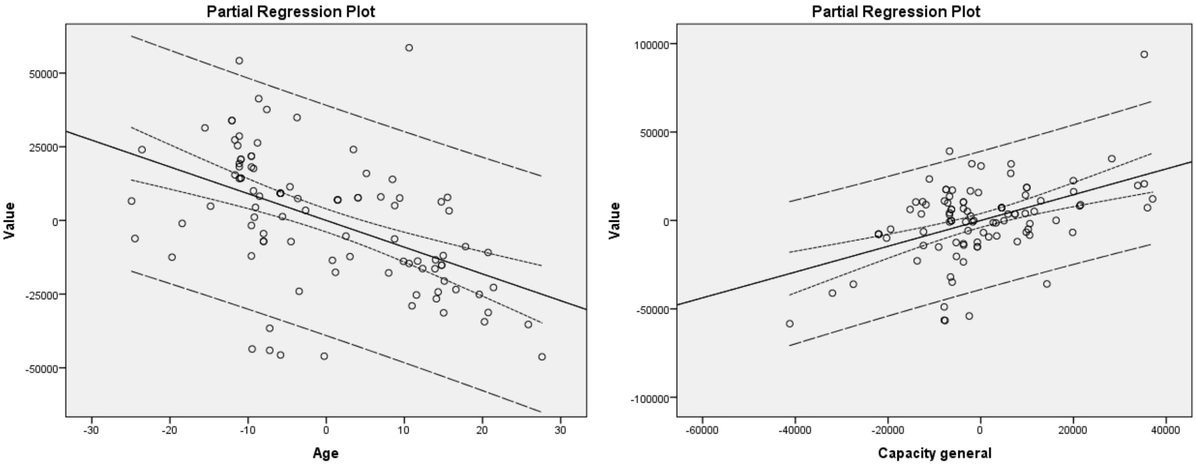


Figure 40: Confidence intervals Age and Value (l) & Capacity and Value

When assessing the confidence bands for the coefficient of *Capacity general*, satisfactory confidence bands are found. A value of zero for the coefficient is unlikely, confirming statistical significance. For very low capacities, wagon value may be overestimated slightly.

Figure 41 shows the relationship between *Axle diameter* and *Value* and the corresponding confidence interval. It can be interpreted that zero lies not within the interval, supporting statistical significance. However, given the widely diverging bands, variation in the coefficient value due to sampling error is relatively high.

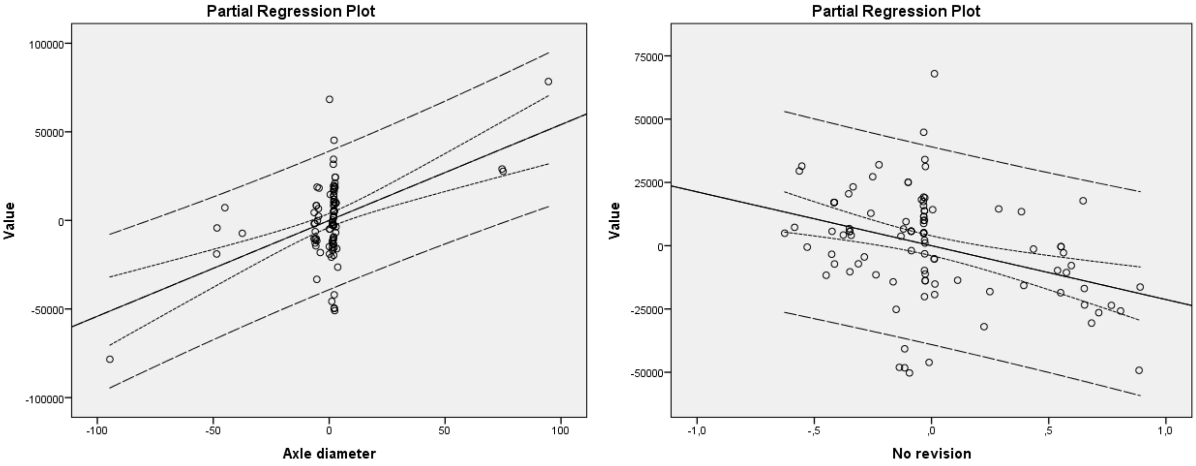


Figure 41: Confidence intervals Axle diameter and Value (l) & No revision and Value (r)

The coefficient for *No revision* (Figure 41) shows that the confidence bands do not include zero as a coefficient value. This confirms statistical significance. The expected variation of the estimated coefficient due to sampling error is reasonable.

Figure 42 gives insight in the confidence interval for the regression coefficient for break-bulk wagons. It shows that zero is not part of the confidence interval, but the confidence bands do leave room for a coefficient value of nearly zero. As a result, the possibility exists that more observations of low-valued break-bulk wagon sales decrease the responsiveness of value on this sector variable.

As found for break-bulk wagons, the confidence band for car transporters widens (Figure 42). Especially for this sector, this is the result of a few, but valid, observations with very high values. Zero is not a value that lies within the confidence interval, establishing statistical significance.

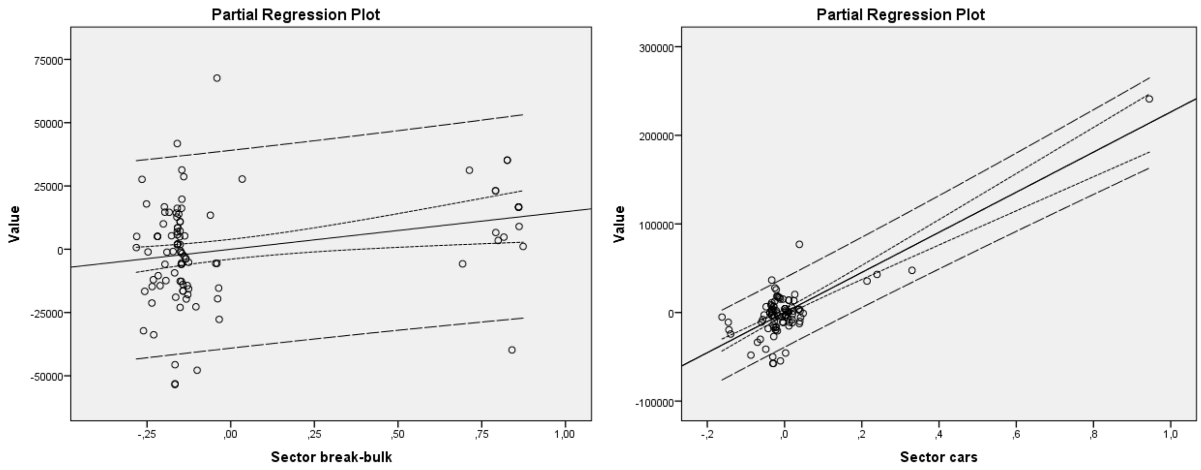


Figure 42: Confidence intervals Sector break-bulk and Value (l) & Sector cars and Value (r)

Appendix A13: Non-linear model specification and results

Visual evaluation of the linear models and relationships between the explanatory factors and vehicle value hint at the existence of non-linearity. Especially for *Age* and *Power rating primary* this is most apparent. Using the same approach as for linear models, new models are created. This time, quadratic variables are added to research if non-linear influences on value exist.

A13.1 Locomotives

For locomotives, *Age^2*, *Index passenger market^2*, *Index freight market^2*, *Gauge^2*, *Number of axles^2*, *Power rating primary^2*, *Number of voltage systems^2*, *Number of country approvals^2* and *Speed^2* are created and used as input with their metric counterparts. Similar to the linear model, corrections are made manually in case of multicollinearity between explanatory factors.

After creating a model using the stepwise function, a higher Adjusted R2 value is observed (Table 77), namely 88.9% instead of the 83.3% of the linear model. This matches the expectation the linear model was not able to explain a part of the variance due to the existence of non-linear effects.

Included explanatory factors are *Age, Age^2*, *Power rating primary*, *Power rating primary^2*, *Number of country approvals^2*, *Speed^2*, *Manufacturer Eastern Europe* and *Sector shunter* (Table 78). All coefficient signs are as expected. High multicollinearity is found between the metric variables and their quadratic counterparts, as expected. Note: *Age* vs. *Age^2* and *Power rating primary* vs. *Power rating primary^2*.

Table 77: Model summary (non-linear) - Locomotives

R	R^2	Adjusted R^2	Std. Error of the Estimate
.946	.896	.889	491,026

Table 78: Coefficients (non-linear) - Locomotives

Locomotives (Adj. R^2 = 88.9%)									
	Unstandardized coefficients		Stand. coefficients			95% Confidence interval for B		Collinearity statistics	
	B	Std. Error	β	t	Sig.	Lower bound	Upper bound	Tolerance	VIF
Constant	523,117	193,930		2.697	.008	139,116	907,117		
Age	-86,385	7,927	-1.312	-10.897	.000	-102,082	-70,689	.060	16.561
Age^2	1,042	148	.876	7.042	.000	749	1,334	.057	17.661
Power rating primary	1,128	131	1.637	8.626	.000	869	1,387	.024	41.157
Power rating primary^2	-.123	.018	-1.206	-7.023	.000	-.158	-.089	.030	33.694
Speed^2	18	6.9	.135	2.594	.011	4	32	.321	3.111
Number of country approvals^2	32,890	7.340	.161	4.481	0.00	18,356	47,423	.674	1.483
Manufacturer Eastern Europe	-508,111	113,019	-.139	-4.496	.000	-731,900	-284,322	.911	1.098
Sector shunter	591,311	165,405	.171	3.575	.001	263,793	918,830	.384	2.606

Table 79: Residuals Statistics (non-linear) - Locomotives

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-600,773	5,260,521	1,894,988	1,393,923	128
Residual	-1,002,916	1,176,008	.000	475,309	128
Std. Predicted Value	-1.790	2.414	.000	1.000	128
Std. Residual	-2.042	2.395	.000	.968	128

The outcomes are realistic in several ways. Firstly, the effect of age on locomotive value is still negative, but thanks to the addition of a quadratic element, the decrease in vehicle value slowly becomes less over the years.

The opposite is the case for the power rating of locomotives, which has a strong positive linear effect on vehicle value. However, thanks to the inclusion of a negative quadratic effect, the effect of increased power rating on value slowly becomes less with increasing power rating.

The inclusion of quadratic effects for *Speed* and *Number of country approvals* matches the expectations created after an ex-ante linearity check (Appendix A5). For both variables, linearity is not inappropriate, but the scatterplots hinted at strongly increasing vehicle values for increased maximum speeds and higher number of country approvals too. This showed the risk of overestimating vehicle value for low speeds and few country approvals, as well as underestimating locomotive value for higher speeds and many approvals.

Thanks to the addition of non-linear variables, the partial regression plots (Figure 43 to Figure 46) now provide less doubt whether relationships are linearity or not: non-linear effects between explanatory factors and locomotive value exists.

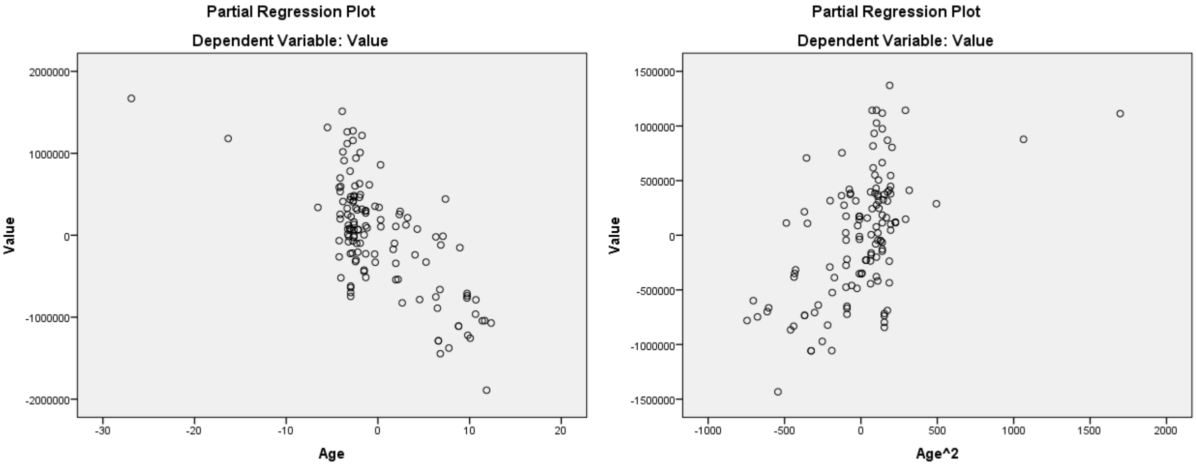


FIGURE 43: PARTIAL REGRESSION PLOTS AGE AND VALUE (L) & AGE^2 AND VALUE (R)

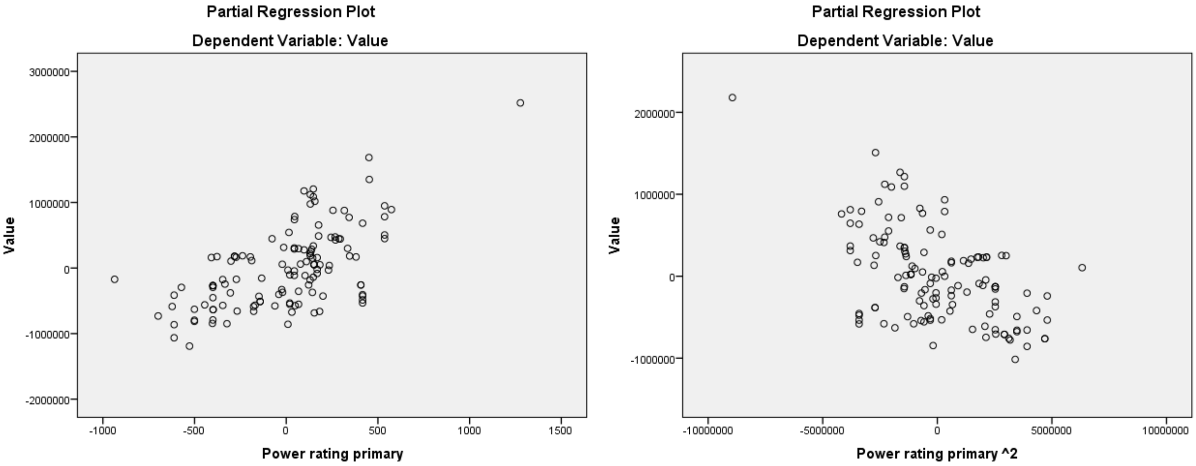


FIGURE 44: PARTIAL REGRESSION PLOTS POWER RATING PRIMARY AND VALUE (L) & POWER RATING PRIMARY^2 AND VALUE (R)

At a sample size of 100 cases and a power of 0.80, the minimum R^2 value that can be found statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. For a sample size of 250 cases, it lies between the 5% and 6%. Using 128 cases, the minimum R^2 values are sufficiently low and explanatory power is sufficient.

Generalizability of the outcomes is maintained, albeit a bit lower than for the linear model. With 128 cases and eight variables, the ratio is 16 cases per independent variable. This is still within the preferred range of 15 to 20.

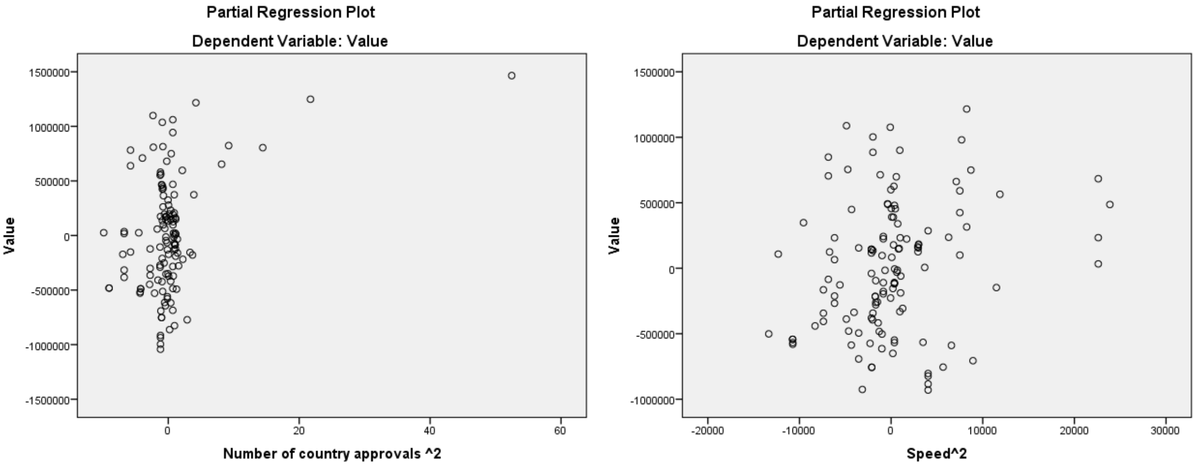


Figure 45: Partial regression plots Number of country approvals^2 and Value (l) & Speed^2 and Value (r)

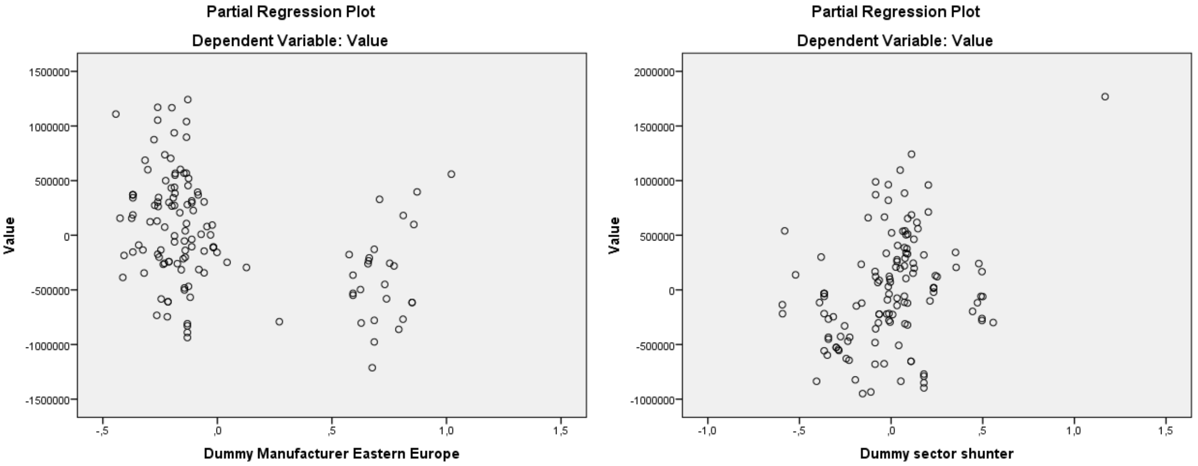


Figure 46: Partial regression plots Dummy manufacturer Eastern Europe and Value (l) & Dummy sector shunter and Value (r)

Any outliers in visible in the partial plots are valid cases. Excluding them from the analysis does not result in substantially different outcomes for coefficient or the R^2 values.

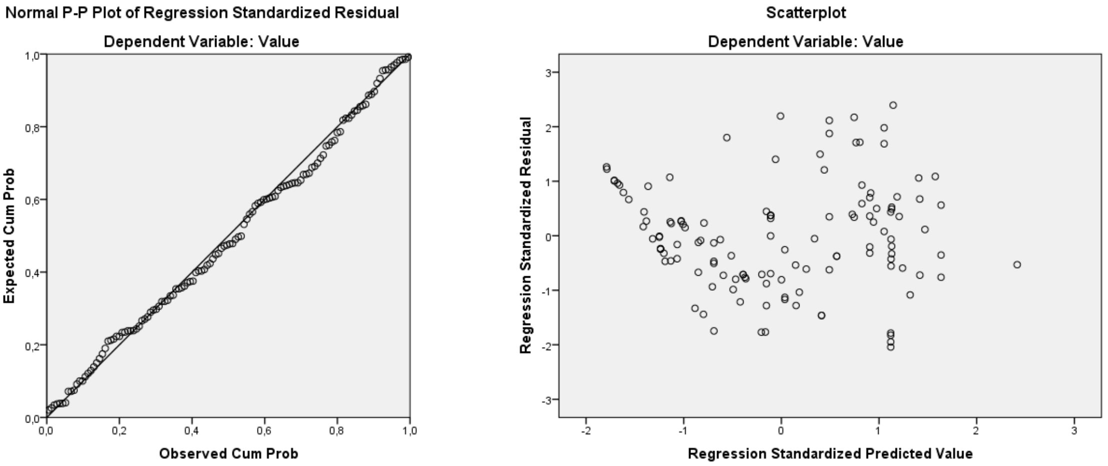


Figure 47: Normal Probability Plot (l) & Standardized Residuals (r)

The normal probability plot of the standardized residual for the locomotive model is visualized in Figure 47. The values are in line with the diagonal, the assumption of normality for the prediction error term is met.

The scatterplot shows the standardized residual plotted against the standardized predictive value. There is no clear pattern of increasing or decreasing residuals, which indicates homoscedasticity. Naturally, linearity is not appropriate and the original doubt when assessing the linear model is in place.

A13.2 Freight wagons

The following quadratic variables are created: *Age*^{2}, *Index freight market*^{2}, *Number of axles*^{2}, *Speed loaded*^{2}, *Speed unloaded*^{2}, *Tare weight*^{2}, *Capacity general*^{2} and *Axle diameter*^{2}. Of these variables, multicollinearity exists between two sets of variables:

- *Number of axles*, *Tare weight* and *Capacity general*
- *Speed loaded* and *Speed unloaded*.

To prevent multicollinearity only *Capacity general* and *Speed loaded* are further used for analysis.

An initial attempt to build a model using the Stepwise function returns a model with a high Adjusted R^2, but with ten explanatory variables: *Age, Age*^{2}*, Capacity general, Axle diameter, Axle diameter*^{2}*, Speed loaded, Brake family other, Sector cars, Sector intermodal* and *No revision*. This is problematic for two reasons:

- Linearity checks show no reason to assume non-linearity between *Axle diameter* and *Value*
- Generalizability of the results becomes problematic due to a very low ratio between the number of explanatory variables and the available number of cases

Excluding *Axle diameter* from the input variables returns a model containing six variables: *Age*, *Age*^{2}*, Capacity general*^{2}*, Sector cars, Sector intermodal* and *No revision*. While this model is more parsimonious, the coefficient of *Capacity general*^{2} returns a value of 6.244E-6, a standard error of .000 and a 95% confidence interval of the unstandardized coefficient with both a lower and upper bound of .000. Therefore, *Capacity general*^{2} is removed.

A third try returns a logical model with the same variables, but with *Capacity general*^{2} replaced by *Capacity general* (Table 81). With an Adjusted R^2 value of 78.4%, it surprisingly returns a 2.8% lower value than the linear model. High multicollinearity is limited to *Age* and *Age*^{2}, as expected.

Table 80: Model summary (non-linear) - Freight wagons

R	R^2	Adjusted R^2	Std. Error of the Estimate
.893	.797	.784	21,534

Table 81: Model results (non-linear) - Freight wagons

Freight wagons (Adj. R^2 = 78.4%)									
	Unstandardized coefficients		Stand. coefficients			95% Confidence interval for B		Collinearity statistics	
	B	Std. Error	β	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
Constant	32,017	11,623		2.755	.007	8,930	55,104		
Age	-2,381	447	-.916	-5.324	.000	-3,269	-1,492	.075	13.311
Age^2	36	9.596	.603	3.704	.000	16	55	.084	11.891
Capacity general	.792	.161	.329	4.911	.000	.471	1.112	.496	2.018
No revision	-16,361	6033	-.148	-2.712	.008	-28,345	-4,378	.747	1.339
Sector cars	168,785	16,153	.518	10.449	.000	136,700	200,871	.907	1.102
Sector intermodal	-12,425	5.837	-1.07	-2.128	.036	-24,020	-829	.888	1.126

Table 82: Residuals Statistics (non-linear) - Freight wagons

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-10,292	241,966	57,360	41,384	98
Residual	-78,034	78034	.000	20,857	98
Std. Predicted Value	-1.635	4.461	.000	1.000	98
Std. Residual	-3.624	3.624	.000	.969	98

Although the non-linear model can explain slightly less variance in wagon value than the linear one, the results are more realistic. The inclusion of *Age*^{2} causes the decrease in value for an increase in *Age* to become less at higher ages. Extremely high ages, which cause an increase in value again due to the nature of the relationship, will not occur.

This is in line with the observation made as part of the ex-ante linearity check, which did not fully discard a linear relationship but which also left room for such a non-linear relationship. Theoretically, the non-linear effect matches the principle of a bottom value. The partial regression plots (Figure 48-Figure 50) show a more definitive linear effect of both *Age* and *Age*^{2} on *Value*, corrected for the other variables in the model.

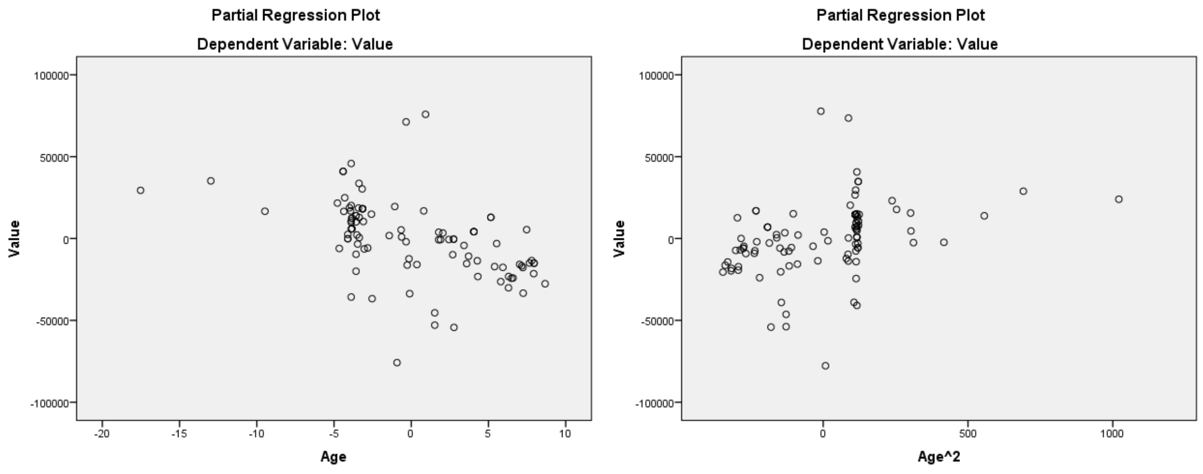


Figure 48: Partial regression plots Age and Value (l) & Age^2 and Value (r)

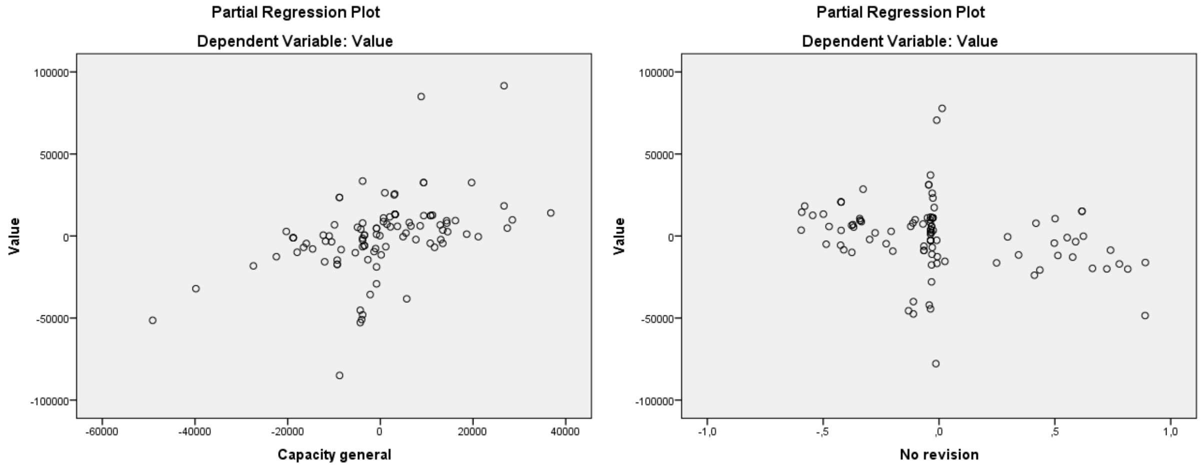


Figure 49: Partial regression plots Capacity general and Value (l) & No revision and Value (r)

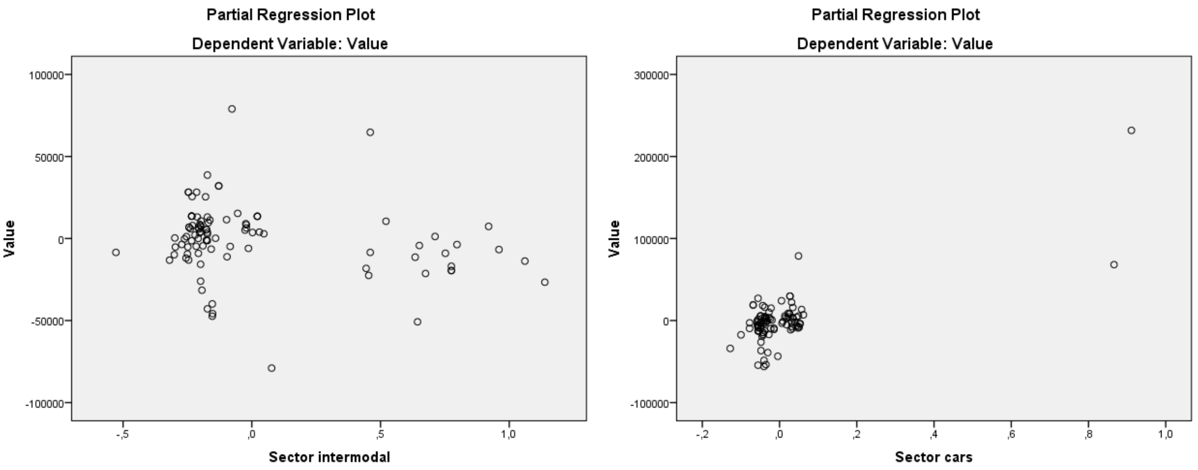


Figure 50: Partial regression plots Sector intermodal and Value (l) & Sector cars and Value (r)

To estimate the freight wagon model, 98 cases are used. The result is an Adjusted R^2 of 78.4%. For 100 cases and a power of 0.80, the minimum R^2 value that can be found statistically significant lies between the 12% and 15% for 5 and 10 independent variables respectively. Also here, the minimum R^2 values are sufficiently low, so the explanatory power is sufficient.

Generalizability of the outcomes is maintained here too. With 98 cases and 6 variables, the ratio remains at 18.3 cases per independent variable. This is within the preferred range of 15 to 20.

Normality of the error term of the variate holds, despite a more s-shaped curve of the plot (Figure 51). No strong departures from the diagonal are observed.

Additionally, the scatterplot shows no clear pattern of increasing or decreasing residuals, which indicates homoscedasticity. Naturally, linearity is not appropriate and the original doubt when assessing the linear model is in place.

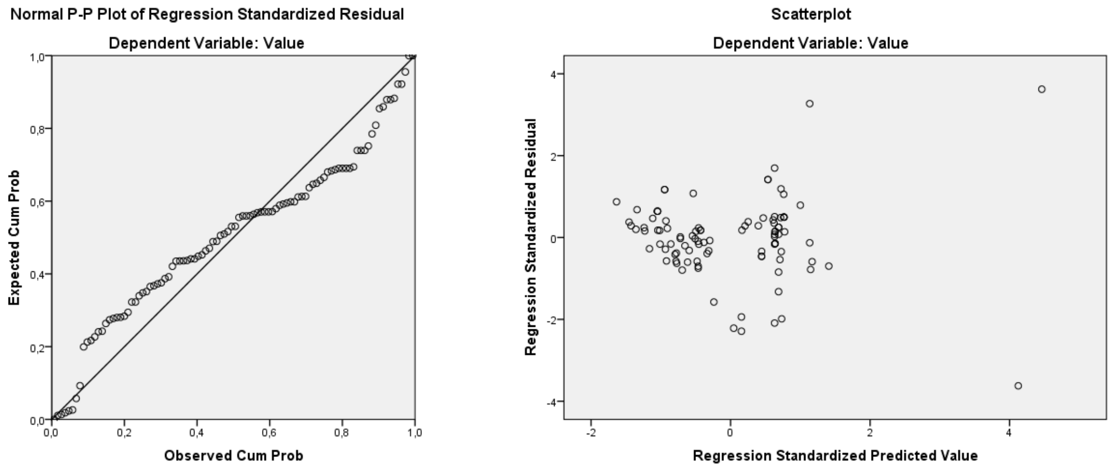


Figure 51: Freight wagons (non-linear) - Normal Probability Plot (l) & Standardized Residuals (r)

Appendix A14: Partial F-tests

This appendix provides insight in the F-tests done to determine whether the non-linear models are preferred over the linear ones.

A14.1 Locomotives

For the two locomotive models, a partial F-value is calculated through the formula:

$$F_{partial} = \frac{((43338024580000 - 28691721430000)/(8-7))}{(28691721430000/(128-8-1))} = 60.7461$$

Equation 40: Partial F-value

Looking up F(0.05,1,119) in a F-table, a F-value is found for F(0.05,1,120) of 3.9201. The calculated F-value is higher than 3.9201, so we can conclude that the non-linear model is the preferred mode. The increase in explained variance is significant.

Table 83: ANOVA results locomotive models

ANOVA					
Model	**Sum of Squares**	**Df**	**Mean square**	**F**	**Sig.**
Locomotives - Linear					
Regression	232117285000000.000	7	33159612140000.000	91.817	.000
Residual	43338024580000.000	120	361150204800.000		
Total	275455309600000.000	127			
Locomotives – Non-Linear					
Regression	246763588100000.000	8	30845448520000.000	127.933	.000
Residual	28691721430000.000	119	241106902800.000		
Total	275455309600000.000	127			

A14.2 Freight wagons

For freight wagons, the calculation of a partial F-value is not possible because the degrees of freedom (Df) do not differ. The R^2-value of the non-linear freight wagon model is slightly lower than for its linear counterpart. This is the result of an individual variable being removed and replaced by the quadratic counterpart of *Age*, namely *Age*^{2}. As a result, the non-linear model explains slightly less of the variance in value, but the shape of the relationship between a vehicle's age and its value is respected better.

Table 84: ANOVA results freight wagon models

ANOVA					
Model	**Sum of Squares**	**Df**	**Mean square**	**F**	**Sig.**
Freight Wagons - Linear					
Regression	171499268200.000	6	28583211370.000	70.646	.000
Residual	36818499890.000	91	404598899.800		
Total	208317768100.000	97			
Freight Wagons – Non-Linear					
Regression	166121770200.000	6		59.710	.000
Residual	42195997960.000	91			
Total	208317768100.000	97			