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Public transport: Energy efficiency of light train systems

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Energy Efficient Transport Systems - ENERGY EFFICIENT PUBLIC TRANSPORT

SESSION II / Lecture 8

THE MALTESE PROJECT

The MALTESE project is a European research project dealing with **energy management and efficiency in Light Rail Transit** (LRT). It is funded under the framework of the SAVE II Programme by the European Commission (Directorate General XVII). MALTESE aims at the horizontal assessment of the energy efficiency of LRT systems and the factors likely to increase that efficiency. The project analyses the energy balance of existing LRT systems (ex post), identifies the factors most important for energy consumption and simulates the energy consumption of planned systems (ex ante) to allow more energy-sensitive planning. A handy planning tool developed to assess the energy balance of planned LRT systems for different planning stages is one major outcome of this project.

Table 1 Key facts about the MALTESE project

Project Title	**M**anagement and **A**ssessment of **L**ight **T**rains for **E**nergy **S**aving and **E**fficiency
Project Funding	funded under the framework of the **SAVE II Programme** by the European Commission (Directorate General XVII)
Duration	**30-months project** starting in January 1997
Partners	**Consortium** of 6 partners: o Environment Transport & Planning, Madrid (Spain) o Ingegneria dei Trasporti, Rome (Italy) o Ingenieurgruppe IVV-Aachen, Aachen (Germany), Project Co-ordinator o SEMALY Transportation Engineering, Lyon (France) o Transport & Travel Research Ltd, Lichfield (Great Britain) o Transport Infrastructure & Telematics, Brussels (Belgium)
Major results	**Set of pan-European guidelines** given as recommendations to politicians and transport planners as well as to people involved in energy management in order to increase the efficiency of LRT systems **Handy Energy Balance Archetypal model** (handy EBA model) for calculating and assessing the energy consumption of planned LRT systems

MALTESE results in a set of **Pan-European guidelines** given as recommendations to politicians and transport planners as well as to people involved in energy management. The project includes several dissemination activities such as a MALTESE web-site (http://www.ivv-aachen.de/maltese/index.htm) established in different languages. Additionally, software tools developed by the MALTESE project are included in the MALTESE manual which is available in CD-ROM format. For key facts about the project refer to Table 1.

IDENTIFICATION OF ENERGY CONSUMPTION CRITERIA FOR LRT SYSTEMS

Light rail vehicles (LRVs) are a **derivative of the traditional tram**, designed to have a greater passenger capacity and speed (but not as high as in a metro system), and a greater level of comfort. LRT systems seem to be a very attractive option for urban public transport, considering their role in promoting energy-efficient and environmentally-friendly transport through a high quality image.

The **methodological approach** is (1) to identify the most relevant endogenous and exogenous energy-related factors and (2) to classify the criteria which enable the definition of the energy efficiency trade-offs, and the factors which influence energy consumption and emissions. This allows (3) to establish quantified indicators of the variance of energy efficiency parameters in different contexts. For a list of energy consumption criteria derived from this approach see Table 2.

Table 2 List of energy consumption criteria

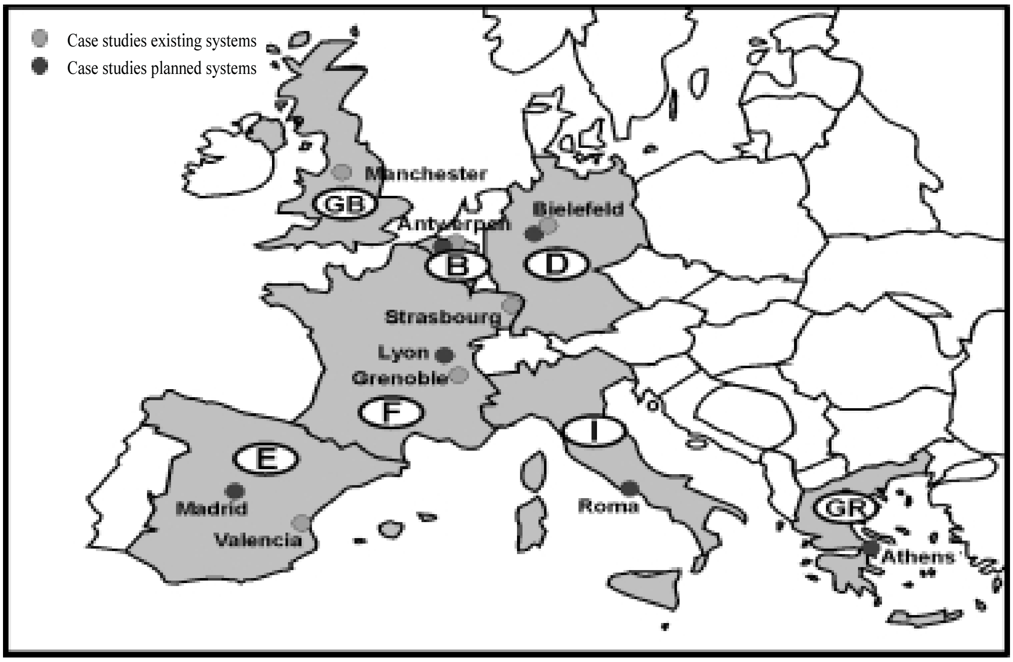
Line Characteristics	Operation Characteristics	Vehicles Characteristics
length	running frequency	motor characteristics / power
gradients	operating speed	empty weight
curves	dead kilometreage	cabin size/capacity
no. stations	door operation	regenerative braking
length of interstations	**Climatic Characteristics**	no./ size of doors
length of tunnels	average temperature	window opening
Crossroads	no. freezing days	cabin lighting
manoeuvring area	humidity	air conditioning
Station Characteristics	**Fixed Facilities Characteristics**	ventilation
lighting (surface)	losses in cables (resistances)	heating
lighting (underground)	losses in rails (resistances)	**Demand Characteristics**
electronic equipment (surface)	switch heating	no. passengers
electronic equipment (undergr.)	rail signalling	passengers kilometres
Electromechanical equipment		load volume

In order to analyse the energy efficiency of LRT systems in detail, a **data collection** covering case studies of different types of LRT systems available in Europe - from Ultra Light Tramway to Pre-Metro and Suburban Rail - was performed (Antwerp, Athens, Bielefeld, Grenoble, Lyon, Madrid, Manchester, Rome, Strasbourg, Valencia; cf. Fig. 3). To exploit these data comprehensively, a homogeneous collection method was defined in order to achieve comparable results.

The **collected data** from the case studies are used

o to identify and eliminate factors with no or a rather small scale influence on energy consumption,
o to design the EBA model (data availability and data requirements),
o to validate the EBA model results with real-world figures on energy consumption,
o to analyse the data availability at different planning stages when planning a new LRT system,
o to provide typical or medium values (default values) to quantify energy consumption for planned LRT systems using one of the 3 handy EBA models.

Fig. 3 Map of MALTESE case study sites

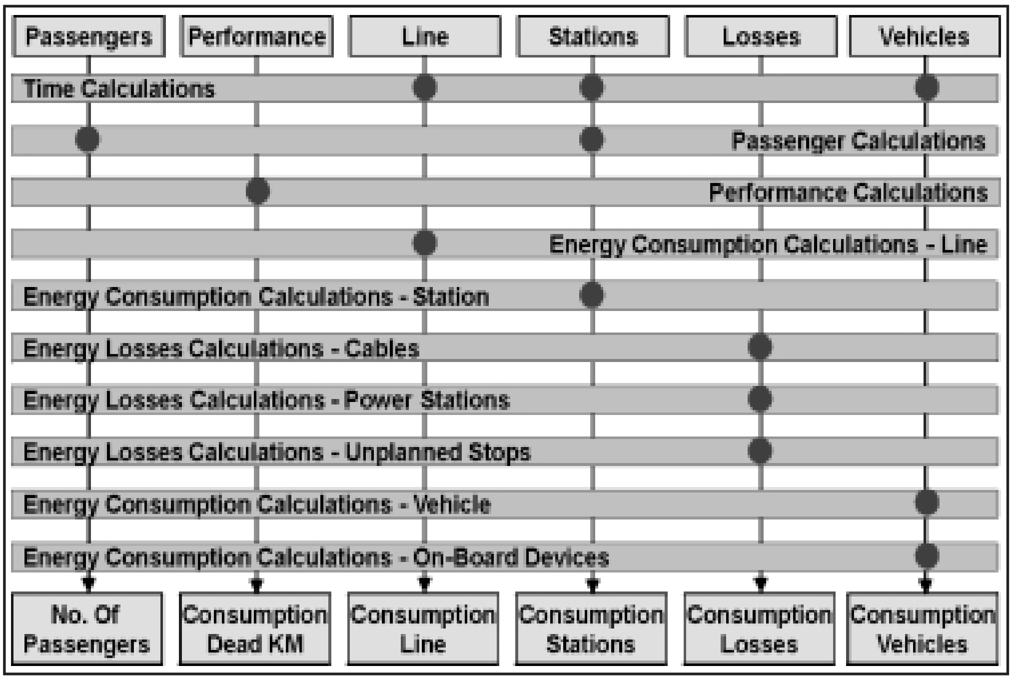


THE ENERGY BALANCE ARCHETYPAL MODEL

The Energy Balance Archetypal (EBA) model is a tool developed by the MALTESE consortium for **the energy consumption calculations of existing LRT systems**. The model comprises all aspects related to the energy consumption of the vehicles, their operation and the infrastructure (line, stations) and their interaction with external factors (e.g. demand, climate).

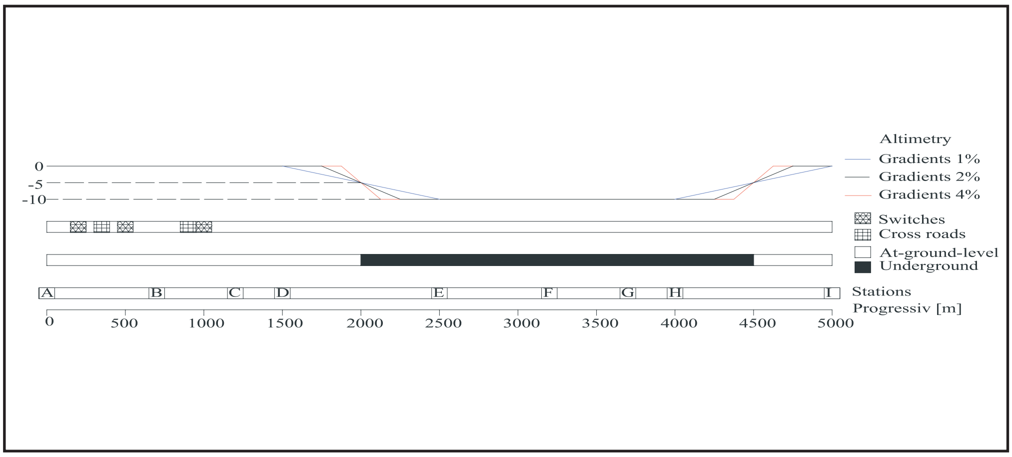
The model is composed of a number of spreadsheets in the Microsoft Excel data format. The **results** are obtained on an annual basis for the various aspects of energy consumption of an LRT system. The validation of the model shows that the difference between measured and calculated values is well in the range of ±10%. The overall model structure is shown in Fig. 4.

Fig. 4 Structure of the Energy Balance Archetypal Model (EBA Model)



In order to assess the relevance of various energy efficiency factors of LRT systems and to evaluate their relevance for the overall energy balance, the EBA model is used to perform a **sensitivity analysis** by defining a test LRT line and changing several parameters to check their contribution to the overall energy balance. The test line considers all elements usually found in LRT systems (Fig. 5).

Fig. 5 Test line description



The overall energy balance of an LRT line is composed of **three main components**: (1) vehicle consumption, accounting for 45.7% of the overall balance, (2) infrastructure consumption, 48.9% and (3) losses in cables, 5.4%, These figures are related to the test LRT line conditions.

EBA AS A SOFTWARE TOOL FOR PLANNED CASES

A major objective of the MALTESE project is to **estimate the energy consumption for planned LRT systems**. For that, the MALTESE EBA model which allows the energy consumption calculation of existing systems is refined by developing 3 self-standing handy models to calculate the energy consumption of planned LRT systems. They serve as a decision support tool, especially targeted to transport planners.

The first step towards a software tool for planned LRT systems is the definition of the **main planning stages** when designing a new LRT system. The following three general stages are seen: feasibility study, alternatives and preliminary plan, exploitation plan. Data availability varies between these three stages.

A database featuring the information usually available for each planning stage is obtained by checking the data availability of the case studies' results for planned LRT systems. Data necessary to perform energy consumption calculations, but usually not available in a planning stage, is generated by developing procedures and methods (proxies, medium values, etc.) to complete the required database. **The programming of 3 simplified versions of the EBA model** (in accordance with the identified 3 main planning stages) is the result of this phase.

GUIDELINES FOR ENERGY EFFICIENT LRT PLANNING AND OPERATION

The MALTESE findings result in a **set of Pan-European guidelines** for energy efficiency in the design, implementation and operation of LRT systems. The guidelines improve standards and procedures assigned to planning, designing, implementing and operating LRT systems and are mainly targeted to transport policy and planning.

The MALTESE project has helped to identify which components and parameters have a real influence on the energy consumption and which of them can be improved. The guidelines are structured by a **parameter-by-parameter approach** pointing out all parameters that have an influence on energy consumption. If available, suggestions/options to reduce the energy consumption of LRT systems are presented. Thus the recommendations serve as a starting point for further initiatives in terms of energy efficient implementation and operation of LRT systems. The parameters considered by the MALTESE guidelines as well as their estimated influence on energy consumption are shown in Table 6.

Table 6 Influence of different parameters on energy consumption

Parameter	high	medium	low	negligible
A. Gradients		■	■	
B. Curves of the line		■	■	
C. Stations				
C.1 Total number of stations		■	■	
C.2 Ticket vending / validating machines etc.			■	■
D. Length of interstation 1)		■	■	
E. Crossroads 2)	■	■	■	
F. Switches		■	■	
G. Manoeuvring areas				
G.1 Number of manoeuvring areas 3)			■	
G.2 Signalling panels/lights				■

H. Underground section				
H.1 Tunnel equipment			■	■
H.2 Underground stations	■	■		
H.3 Lighting and ventilation	■			
H.4 Escalators and lifts		■		
I. Surface section: station lighting			■	■
J. Running frequency and amplitude	■			
K. Location of the depot	■	■		
L. Stop operation	■			
M. Climatic conditions		■	■	
N. Fixed facilities				
N.1 Substations			■	■
N.2 Line: feeder and rail			■	
N.3 Switch heating 4)		■	■	
O. Vehicles				
O.1 Doors		■	■	
O.2 Lighting			■	
O.3 Ventilation		■	■	
O.4 Window opening			■	
O.5 Heating system / air conditioning		■		
O.6 Traction / braking	■			
O.7 Rolling stock weight	■			

Remarks
1) directly linked to the number of stations
2) largely depending on the number of crossroads
3) medium to high in combination with other parameters influencing acceleration/deceleration
4) depending on the local temperatures and number of switches

The guidelines concentrate on those components causing high energy consumption and offer high potential to increase their efficiency. An excerpt of the guidelines is shown in Table 7.

Table 7 Excerpt from the MALTESE guidelines

E. Crossroads	
Parameter information / description	In many LRT networks, crossroads increase the energy consumption especially in the city centre, because the vehicle has to stop more frequently at crossroads due to a higher traffic density.
Influence on energy consumption	Low to high, depending on the number of crossroads
Suggestions / options to reduce energy consumption	Model simulations have shown that, from an energy savings point of view, it is better to stop a vehicle less frequently for a longer time instead of doing more frequent and shorter stops. **The best solution is to adopt an AVL system giving absolute priority to the LRV. It guarantees at the same time a reduction of (1) the energy consumed by the vehicle and (2) running time.** **If it is impossible to adopt such a system, the easiest solution is to locate the stations as close as possible to the crossroads.** **Another possibility to reduce the energy consumed due to starts and stops is an onboard energy recapturing system. The energy regenerated can be used for station lighting and associated systems, especially for underground stations where the overall consumption is important.**

H. Underground section	
H.2 Underground stations	
Parameter information / description	Usually, underground stations of an LRT network are only located in the city centre.
Influence on energy consumption	Medium to high
Suggestions / options to reduce energy consumption	**Because an underground line consumes much more energy than the corresponding line at ground level, the theoretical solution is to adopt ground level lines in protected sites wherever possible. But, even from an energy consumption point of view, the construction of underground segments is justified, if (1) the same trunk is shared by a number of lines or (2) due to a high traffic density at surface level an undisturbed operation of a frequent LRT line is impossible.**
H.3 Lighting and ventilation	
Parameter information / description	Lighting and ventilation form a part of the electromechanical equipment needed to operate an underground station.
Influence on energy consumption	High
Suggestions / options to reduce energy consumption	Energy consumption of lighting is really more important in underground stations. **Paint the underground station with bright colours capable to reflect the light.** **Use a minimum of lighting. The lighting can be minimised to a light intensity which ensures safe operation of the LRT service. Keep to the respective technical standards.**

J. Running frequency and operating time	
Parameter information / description	The running frequency of the service and the operating time of a network are - together with the rolling stock comfort - major key factors its success.
Influence on energy consumption	High
Suggestions / options to reduce energy consumption:	The best way to reduce energy consumption is to perform a precise analysis between demand and frequency in order to find the optimum frequency and - if possible - to reduce the operating time to a minimum, especially during off-peak hours.

K. Location of the depot	
Parameter information / description	This parameter can have an important influence depending on the exact location of the depot and other operational as-pects.
Influence on energy consumption	Medium to high
Suggestions / options to reduce energy consumption	**The energy consumed by the rolling stock between depot and line is 100% "lost". A logical conclusion is that the depot should be located as close as possible to the line and - more precisely - as close as possible to a sta-tion.** **For the same reason, it is preferable to park the LRVs on the line during the day instead of parking them in the depot.** **If the depot for some reasons cannot be located near to the line, put basic "stop-on-demand" stations between depot and line and offer such trips as commercial services.**

O. Vehicles	
O.6 Traction / braking	
Parameter information / description	As outlined in the sensitivity analysis, the bulk of energy used by the LRV is needed to accelerate and is lost when braking.
Influence on energy consumption	High
Suggestions / options to reduce energy consumption	**Traction / braking power system improvements: Because of new developments in the field of electronic traction systems it is possible to use rheostats for asynchronous motors controlled by voltage inverter and variable frequencies instead of direct current-motorised traction / electrical braking equipment at Light rail vehicles, too. Electronic traction equipment controls the start of the vehicle with very low losses as well as the regenerative braking (conversion from kinetic energy to electric energy). Additionally, electronic traction equipment prevents the thermal losses in the rheostats.** **Tare reductions: It must be taken into account that the vehicle is stressed by high and frequent accelerations (1.2m/s^2 every 2 to 3 minutes as an average). Propulsion energy consumption is nearly proportional to the mass of the vehicle.** **Use mechanical brakes with hydraulic jacks instead of pneumatic ones.**
O.7 Rolling stock weight	
Parameter information / description	The energy consumption for propulsion is nearly proportional to the weight of the vehicles (and its passenger load).
Influence on energy consumption	High
Suggestions / options to reduce energy consumption	**From an energetic point of view, the best solution to save energy would be to use vehicles of different length according to the period of the day and the load of the line. Therefore, run with two vehicles coupled in peak hours and with single vehicle in off-peak hours.** **Use light materials as in aeronautics (sandwich structures, composites, …) which offer high stability and low weight.**