Investigation of appropriate mass for electronically assisted pedal cycles

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INVESTIGATION OF APPROPRIATE MASS FOR EAPCS

Client: Department for Transport, Cleaner Fuels & Vehicles Division

(Steve Sopp)

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Executive summary

An Electrically Assisted Pedal Cycle (EAPC) which complies with the legislation is not considered to be a motor vehicle within the meaning of the Road Traffic Act 1988. As a result, it is not required to be registered, pay vehicle excise duty (road tax) or be insured as a motor vehicle. No EAPC may be ridden by anyone under the age of 14 years.

An EAPC is not exempt from having either a European Certificate of Conformity or an individual pre-registration assessment if it is fitted with pedals and a motor that can provide power assistance (also known as ‘twist and go’) at any time without the rider pedalling, or if the motor is not cut off automatically when the vehicle reaches 25km/h. However, if it is within the scope of the EAPC Regulations, it still does not require registration, licensing or insurance.

It is understood that the DfT are considering a review of the British legislation regarding EAPCs following the publication of new draft standards being developed by CEN, the European standards body. In undertaking this work it is imperative that potential alterations to current standards are investigated so that safety is not compromised. One such difference is that, unlike British legislation, the draft CEN standard does not include a mass limit.

In order to examine the potential risks and benefits of changing the legislation TRL has correlated and reviewed information relevant to the mass limit. The areas which were identified as relevant to the mass limit were the legislation of other countries, the strength of riders, the effect of mass on the stability of cycles, the effect of mass on braking, the implications for tyres, whether or not the mass of EAPCs would be limited by other factors without a limit and accident data regarding EAPCs.

As part of this, the archives of TRL, the DfT and the National Archives were searched for documents related to EAPCs. While no relevant information was found in the TRL archives, several files were found at both the National Archives and the DfT. The documents from these files were reviewed and any relevant information collated and presented.

It was not possible to identify a single reason behind the mass limit from these documents; however, several reasons were discussed and so one or more of these could have been part of the reasoning. These reasons were as follows:

- **Centre of gravity height**: The increased mass could change the centre of gravity height of an EAPC, which could affect the stability and handling. The mass limit would limit both the change in centre of gravity height and the effects of the change.

- **Mass limit to limit performance**: A mass limit was considered as a method of limiting EAPC performance. It was suggested that a mass limit would limit the battery capacity of an EAPC, and therefore the motor performance available. Since the final regulations included power output and top speed limits and modern batteries attain a much higher energy density this may be less relevant now than then.

- **Limit the need for third party insurance**: The consequence of an accident involving an EAPC could be greater than those for regular pedal bicycles. The mass limit was considered as a way of ensuring that the likely damage caused by an EAPC was limited so that third party insurance remained unnecessary. Section 3.2.1.2 contains a reference to a document which confirms that this was a major consideration in the original drafting of EAPC regulations.

- **Age limit**: The main reason for the lower age limit of 14 years old was to coincide with the age of legal responsibility. This was decided by parliament so that local authorities, if deemed necessary, were able to prosecute riders of EAPCs. While this shows that the strength requirements of riding an EAPC may not have been
considered in setting the original age limit, it remains a factor which could be relevant to the potential removal of the mass limit.

Since no definite reason behind the mass limit was discovered in the search of previous documentation, a review of information likely to be pertinent to the mass limit specification was collated. A brief summary of each point discussed is given below.

The legislation of several countries outside of the UK and Europe were reviewed. It was found that China and some parts of Canada enforce a mass limit in EAPC regulations. The US and Japan, however, do not stipulate a mass limit.

It is possible that an EAPC of increased mass could require greater strength to ride in certain situations than that of a regular bicycle or EAPC which conforms to the current mass limit. In order to investigate whether this is a significant safety risk, anthropometric strength data for actions similar to riding a bicycle were compared between average adults and two groups of people likely to have reduced strength. These groups were children (at the legislated age limit of 14) and older adults. It was found that both groups have reduced strengths in comparison to adults, but it was not possible to confirm whether this would be a safety risk since the “minimum strength” to ride an EAPC of increased mass safely is not known.

The stability of a bicycle is a very complex subject, and as such it was not possible to give definite advice on the effects of mass on the handling. It is likely, however, that the stability of an EAPC may be affected by increased mass, either from the increase of mass itself or by the change of centre of gravity position. A comparison of centre of gravity heights of bicycles, EAPCs and EAPCs of increase mass was also performed. While the calculations were heavily simplified it was found that a large increase of mass of an EAPC did not affect the overall centre of gravity of the rider and cycle combination by a proportional amount.

An increase of mass is likely to have several effects on the tyres and brakes of an EAPC. Assuming the same brake force is applied to an EAPC of increased mass as that of a regular bicycle, it is likely that the EAPC would have a longer stopping distance. However, assuming that the brakes and tyres of an EAPC are capable, an EAPC stopped in the same distance as a bicycle could be less likely to pitch the rider over the handlebars. It should be pointed out that many assumptions were made in this case particularly, and it should not be taken as a general rule. The brakes are also likely to have an increased wear rate in comparison to a regular bicycle since they would have to convert a greater amount of kinetic energy for the same speed reduction. The tyres of an EAPC of increased mass are likely to experience both increased mechanical loading and heat transfer from rim brakes also. It is not possible to ascertain the safety implications of increased mass on the brakes of an EAPC without specific testing.

It could be the case that the mass of an EAPC is somewhat limited by factors other than the regulated limit itself. A user of an EAPC is likely to want the vehicle to handle as much like a bicycle as possible, and as such would prefer a lighter EAPC which is easy to ride and park. Another likely preference of a user of an EAPC is to get the best performance possible. Since there is a power and speed limit, another way by which a manufacturer may achieve this is by giving their cycle good acceleration. One way by doing this is to reduce the mass of the cycle itself, increasing the power to weight ratio.

The information presented only gives an indication of the likely effects of mass on an EAPC. It has not been possible in most cases to give accurate recommendations regarding the effects of mass because there has been very little previous work conducted on bicycles and EAPCs in general. The only way in which to give reliable information regarding the effects of increasing the mass of an EAPC would be to conduct testing specific to the addition of extra mass to an EAPC.
Abstract

It is understood that the DfT are considering a review of the British legislation regarding EAPCs following the publication of new draft standards being developed by CEN, the European standards body. In undertaking this work it is imperative that potential alterations to current standards are investigated so that safety is not compromised. One such difference is that, unlike British legislation, the draft CEN standard does not include a mass limit.

The information presented only gives an indication of the likely effects of mass on an EAPC. It has not been possible in most cases to give accurate recommendations regarding the effects of mass because there has been very little previous work conducted on bicycles and EAPCs in general. The only way in which to give reliable information regarding the effects of increasing the mass of an EAPC would be to conduct testing specific to the addition of extra mass to an EAPC.

Further consideration of factors identified in this initial report is required before any decisions on removing the GB EAPC weight limit are reached.
1 Introduction

The current GB legislation for Electrically Assisted Pedal Cycles (EAPCs) was introduced in 1983 (S.I. 1168/1983). It defines the power of the motor assist and the top speed of the vehicles, and includes a maximum kerbside mass limit of 40kg for bicycles and 60kg for tricycles and tandems. In Great Britain, EAPCs may be ridden without registration, without a license and from the age of 14. Additionally, ‘twist and-go’ EAPCs are permitted (i.e. the rider does not have to be pedalling to use the electrical assistance).

It is understood that the DfT is considering aligning the British legislation regarding EAPCs with that of the new standards being developed by CEN, the European standards body. In order for this decision to be made it is imperative that potential alterations to current standards are investigated so that safety is not compromised. One such difference is that, unlike British legislation, the draft CEN standard does not include a mass limit.

In order to examine the potential risks and benefits of changing the legislation TRL has collated and reviewed information relevant to the mass limit. The areas which were identified as relevant to the mass limit were the legislation of other countries, the strength of riders, the effect of mass on the stability of cycles, the effect of mass on braking, the implications for tyres, whether or not the mass of EAPCs would be limited by other factors without a limit and accident data regarding EAPCs.
2 Method

No original documentation relating to the standard was found in the TRL archives. As a result, the National Archives was searched. This led to a visit to the National Archives, where the relevant files were reviewed, and relevant sections photographed. A summary of these is given in section 3.2, with the complete documents given in Appendix A.

Information gathered at the National Archives also pointed towards a further file of documents which was in the DfT archives, which was requested and reviewed.

These evidence sources were prioritised as they were most likely to reveal the original reasons for the mass limit in the UK regulations.

The remaining project resources were put towards developing a brief review of the possible implications of removing the mass limit and, where possible, providing evidence for the implications from the literature. This information is presented in section 4.

The overall conclusions and recommendations are given in section 6.
3 Previous documentation

3.1 TRL Documents

No documentation regarding the EAPC regulations was found in the TRL archives. This led to the search of the National Archives, which is documented in section 3.2.

3.2 National Archives

The files selected for viewing at the National Archives were as follows:

- MT 191/112: Electrically assisted pedal cycles (VSE 1528/2 Part 2)
- MT 191/117: British Standard Institution (BSI) draft standard safety requirements for bicycles: includes cycling policy statement (VSE 4011/2 Part 1)

From these files several relevant documents were identified, from which summaries are given in the sections below. Full copies of the documents are given in Appendix A.

The file MT 191/112 was found to be the second file in a series, implying there was an earlier file available. This earlier file was found in the DfT archives and was subsequently reviewed. The contents of this file are discussed in section 3.3, along with several other files which were considered likely to contain useful information.

3.2.1.1 Electric power assisted bicycle – Definition

This document is a preliminary specification for EAPCs in the context of exemption from the Road Traffic Act. While this document is not marked with its source, the final sentence indicates that it was drafted by the Department of Transport (now the DfT).

Section 1 of the document outlined the main requirements to be considered to ensure that EAPCs are suitable for exemption from the Road Traffic Act. The first point was that “Bicycle safety and performance characteristics must be retained as far as possible”. This indicates that considerations of the DoT were mainly aimed at ensuring that EAPCs were as similar to bicycles as possible.

Section 3.3 was a list of items which required further investigation, two of which were centre of gravity height definition and the mass limit. The following paragraph states that further discussion would take place between the DoT, TRRL, Lucas Industries and T I Raleigh Ltd.

3.2.1.2 Lucas documents

Two documents were found in the information at the National Archives from Lucas Industries Ltd.

Document dated 9 September 1980

This document was sent to the DoT, and was titled “Battery Assisted Bicycle”. While this document is mainly concerned with the motor power outputs and energy densities of batteries, the first paragraph states as follows:

“When modifying a bicycle, there is clearly a limit to the weight of batteries which can be contained, and in practical terms a battery weighing more than 20 lbs becomes unmanageable.”
This combined with a later comment regarding frame design suggests that in the opinion of Lucas there was a maximum practical weight of battery which can be fitted to an EAPC design which has a similar frame to a bicycle, and as such should be added to legislation in order to keep EAPC design similar to bicycles. It is also implied that a limit of battery mass would help limit the maximum speed of EAPCs due to the limited energy density of battery design of the time.

**Letter dated 12 September 1980**

This document was a letter sent by to the Department of Transport. Following a demonstration of an electric bicycle, this letter was a brief summary of considerations regarded as important in the preparation of EAPC regulations. The following points were raised which are relevant to the mass limit:

- Lucas advised that the power consumption of the cycle is restricted by its weight.
- Lucas thought it impossible to carry the weight of the battery and motor and allow the bicycle to exceed the maximum pedal speed of a regular bicycle unassisted. They considered the maximum pedal speed of a regular bicycle to be 25 mph.
- In addition to mass limits, Lucas also advised that centre of gravity position should be limited. These limitations were suggested so that “it would be impossible to provide a vehicle that would have better performance than a pedal cycle in terms of absolute speed and the fitting of extra equipment would not prejudice the safety of the bicycle”.
- Lucas did not believe that a limited increase of weight would have a drastic effect on the stopping distance of an EAPC. They did not support the addition of moped braking regulations to EAPCs.

**3.2.1.3 Discussion paper on the requirements of EAPCs**

This document was a paper discussing the importance of each of a list of items previously suggested as relevant for inclusion into EAPC regulations. It was referenced in a letter filed before it as authored by Mr P Murphy of the Department of Transport.

The first paragraph of the paper vaguely referenced a previous document from which the list of EAPC requirements was taken. This document was considered likely to be more technical rather than concerned with legislative implications, and so an attempt was made to track it down.

The sections d and e of the discussion paper are relevant to the mass of an EAPC. A brief summary of each is given below:

**Section d**

Section d was concerned with the centre of gravity height of an EAPC. The author suggests that if the centre of gravity is moved too high or too far behind the rear axle by the additional weight of an EAPC then the “machine will be harder to ride and control”. The author also advises that while a centre of gravity height requirement would be beneficial, it would be hard to enforce, especially on bicycle conversion kits or on EAPCs imported from other countries. A further interesting point raised is that bicycles are not limited in terms of load carrying and additional passengers, both of which could have the same effect on the handling of the bicycle.
Section e
Section e was concerned with the mass limit itself. The author suggests that since the range of an EAPC is dependent on the amount of assistance provided, a cycle designed to provide a lot of assistance may have additional batteries added to increase the range. Due to the weight of batteries (especially at the time) this would increase the mass of the EAPC by a large amount. The author advises that a large increase in weight would have the following effects:

- Bicycle tyres and brakes would no longer be suitable
- The handling problems suggested in section d would be exacerbated
- Additional batteries could lead to users increasing the voltage supplied to the motor, increasing its power output

3.2.1.4 TRRL supplied specification
This document was a specification supplied to a company called “Dragonfly Research” by TRRL. This specification was included in a proposal for the development of an EAPC presented to the DoT by Dragonfly Research. While there is no definite evidence of the reasons behind the mass limit, section 5 of the specification defines centre of gravity requirements. This could indicate that there were concerns at TRRL about the stability of an EAPC with a centre of gravity position far outside that of a regular bicycle. Since these requirements were not included in the final regulations this also could indicate that the mass limit was considered sufficient by the DoT to ensure that the stability of a cycle is not compromised by the addition of the batteries and motor of an EAPC.

3.2.1.5 Raleigh letter
This document was a letter from TI Raleigh Ltd, to TRRL. The letter is mainly concerned with outlining Raleigh’s position regarding the market for EAPCs in the UK; however, there is a section which discusses TRRL’s role in the proposal of the regulations.

The following items are identified as important constraints for the definition of an EAPC:

- Machine weight limit of 80 lbs
- Fore/aft and height restriction of the centre of gravity position
- A speed restriction to which motor assistance is provided
- Motor size
- Motor assistance only to be provided whilst pedalling
- Separate energy source only from a battery
- Safety precautions for mains charging

It is noted that the prototypes built by Raleigh largely conform to the draft regulations proposal drafted by TRRL. There is also a note at the end of the letter which clarifies that all the items discussed in the letter were not brought about in conjunction with any other organisation. This indicates that similar safety requirements were identified by both TRRL and Raleigh independently. This could be interpreted as showing that at the time of this letter, centre of gravity position was considered an important safety concern of several organisations involved in work on EAPCs. At some stage later it was decided that simply the mass limit would suffice.
3.2.2 Summary

Although there were no documents found containing conclusive information into the reasons behind the mass limit in EAPC regulations, there were several documents identified at the National Archives which contained useful information.

The main concerns of the DoT and the government whilst drafting the regulations, appeared to be that EAPCs should be legislated to be as similar to bicycles as possible. This was to ensure that they were suitable for exemption from vehicle registration, licensing, insurance and other similar issues under the Road Traffic Act.

There were preliminary assessments of safety considerations regarding EAPCs drafted by several relevant organisations such as TRRL, Lucas and Raleigh. It seems universal that these assessments identify that the position of the centre of gravity is important for vehicle handling in addition to a maximum mass limit. The DoT also identified that it would be very difficult to enforce a centre of gravity height limit on home-made or add-on EAPC kits.

The Lucas document dated 9 September 1980 (section 3.2.2.1) shows there was at least some consideration (by Lucas) given to the mass limit as a potential way of limiting power output and therefore speed of EAPCs. It is suggested that given that an EAPC must have a minimum range, that a limit of battery mass would in effect limit the power output available and therefore the top speed. Whether or not this was considered by the DoT at the time in including a mass limit for EAPCs, it is less relevant today given that battery technology has advanced far beyond the capacities quoted in the document.

3.3 DfT documents

The files which were viewed at DfT were:

- VSE 1528/7 Part 1: Electrically assisted pedal cycle deregulation
- VSE 1528/2 Part 3: Electrically assisted pedal cycles – Policy
- VSE 1528/1 Part 5: Correspondence and general papers - Electrically-assisted bicycles
- VSE 1528/1 Part 6: Correspondence and general papers – Electrically-assisted bicycles

Parts five and six of VSE 1528/1 were found to contain no information relevant to the mass limit. However, VSE 1528/7 Part 1 and VSE 1528/2 Part 3 both contained documents which contain relevant information, which are reviewed in this section.

3.3.1 VSE 1528/7 Part 1: Electrically assisted pedal cycle deregulation

This file of documents was primarily concerned with a working group set up in 1995 to consider the deregulation of EAPCs. This working group consisted of representatives from the Department of Transport (DoT), the Department of Trade and Industry (DTI) and companies in the bicycle industry. The aim of this working group was to assess the possibility of relaxing EAPC regulations so that higher performance vehicles could be designed and still fall under the definition of an EAPC, and as such be subject to the exemptions from the Road Traffic Act.

While this working group was concerned with the regulation of many performance aspects of EAPCs there was discussion of the mass limit. As part of this discussion, there were several documents found in the file which were relevant to both the safety aspects of removing a mass limit, and the original reasoning behind the limit.
3.3.1.1 Points for discussion: Motor assisted human powered vehicle (MAHPV)

This document was produced by Pashley Cycles and outlines their points of discussion for a meeting of the working group on 29 March 1995. As part of this one of the requirements they wanted to remove was the mass limit. This document shows that one of the considerations of the working group was to remove the mass limit, and that manufacturers were in favour of this change in order to reduce restriction on the design and development of electrically assisted vehicles.

3.3.1.2 Working group to consider relaxation of the electrically assisted pedal cycle regulations 1983

This document is an internal letter of the DVLP dated 5 June 1995. It is a response to a previous letter about the proposals being considered by the working group.

The document is relevant to the mass limit regulations since it shows that one of the considerations of the working group was that extra power and weight could cause the consequences of an accident to be far greater. One of the reasons EAPCs were considered suitable for exemption from the Road Traffic Act was that their performance and handling characteristics are very close to those of a regular bicycle; the point put forward in this letter is that without a mass limit some vehicles designed may not be suitable under EAPC regulations if they are heavy enough to cause sufficient damage in accidents to require third party insurance.

3.3.1.3 Chairman’s summary of the work of the electrically assisted pedal cycle (deregulation) working group

This document was a summary of the work completed by the EAPC deregulation working group. This is a fairly comprehensive document detailing all of the avenues explored by the working group; however, there are sections with details of research into and discussion of the mass limit of EAPCs.

Background

The background section of the document makes reference to research into the reasoning behind the original regulations in general. It states that it was found that the age limit of the original EAPC regulations was chosen since it was the age of criminal responsibility. This could be interpreted that the age limit was not concerned with the strength required to ride an EAPC safely.

Safety

The safety section of the document discusses the role of safety in the original regulations. It states that it was found that consideration was given to the effect of the increased mass and centre of gravity height of an EAPC on braking and stability in preparation of the original regulations.

Discussion

The discussion section details all of the considerations by the working group on the implications of a legislative change of the definition of EAPCs. As part of this, section iii of the discussion deals with safety and it is apparent that there was some discussion about possible designs which would be permissible under the suggested options for regulatory change. It is identified that a cycle with a very high centre of gravity (due to battery positioning) could be designed, and that this would be a safety concern in terms of stability and braking. It is also mentioned that it was believed that brake tests require
a level of stability themselves and that the weight limit was introduced “partly to limit the weight of the batteries”.

Appendix A

This section of the document is a brief summary of background information retrieved as part of research into EAPC regulation. Section one states that the earliest paper found was dated April 1981; however, it was clear there was some discussion prior to this date. This paper is referred to as coming from VSE file 1281/2, but it may also have been contained in the file VSE 1528/2 found at the National Archives in section 3.2. This could not be confirmed, however, could be the case since 1528/2 file covers the dates January to December 1981.

The information relevant to the mass limit taken from this early document is as follows

- An EAPC should retain the essential characteristics of a bicycle
- The weight limit is due to a possible raise of centre of gravity
- Maximum weight suggested as 80lb

It is also mentioned in Appendix A that while the power output limit of 200W was "somewhat arbitrary", input from the TRRL and other organisations led to the increased weight and power limits for tricycles. This indicates that some specific consideration or even testing may have been conducted in order to ascertain whether an increased mass and power limit would be safe for tricycles. There are no direct records of this work in the TRL archives, however a reference to TRRL involvement in the design of an electrically assisted tricycle was found (Raymond H, 1983). This document references an appendix which contains the transcript of a meeting held at TRRL regarding the design aspects of an electric tricycle. The document is held at TRL on microfiche, however the appendices are missing. A complete copy of the document has not been located within the timescale of this project.

3.3.1.4 Electrically assisted pedal cycles regulations (Speech notes)

This document was a draft of the speech notes for debate in standing committee. This document gives clear indication that there was a thorough investigative process in order that the specification for EAPCs would ensure that they were safe to ride by all likely users. It specifically mentions that it was parliament that set the minimum riding age at 14 years old. It is also mentioned that work on the specification was carried out at TRRL.

3.3.1.5 Electrically assisted pedal cycles regulations (Q&A briefing)

This document was in addition to the speech notes above, and is a briefing on the questions likely to be asked in parliament. In answering the question “Why 14 years?” it is stated that the age limit was chosen for legal and safety connotations. Firstly from a legal standpoint children over 14 can be prosecuted for committing an offence (e.g. allowing a younger child to ride an EAPC) and from a safety perspective that 14 was considered an age when “children can exercise a measure of judgement and skill”.

3.3.2 VSE 1528/2 Part 3: Electrically assisted pedal cycles – Policy

This file of documents appears to be a continuation of the first file found at the National Archives. As such it contained information pertaining to the drafting of EAPC regulations in general.
3.3.2.1  Electrically Assisted Bicycles (VEDU)

This document was an internal letter within VEDU. The letter is concerned with a visit to TRRL for a demonstration of an EAPC. While the main content of the letter is to do with motor output, section 4 reiterates that one of the reasons behind the mass limit in regulations could have been to try and limit EAPCs in terms of battery and therefore motor power.

3.3.2.2  Definition of Electrically Assisted Cycles (VEDU)

This document was another internal letter within VEDU. This letter is concerned with the definition of EAPCs. Section 2.1 of this letter states:

"Weight – the maximum weight provides a limit on performance of the EAC as it effectively limits battery capacity”.

This is further evidence that one of the reasons for the mass limit was to limit the size of battery which could be used, and therefore the performance of the EAPC in terms of motor output.

3.3.2.3  Electrically Assisted Cycles

This document was a further internal letter. Paragraph 2 of this letter is another reference to the mass limit based on battery capacity. It is also another reference to the performance concerns being related to maintaining the same characteristics as a bicycle, and that the limit of 40kg was rounded up from the metric conversion of 80lbs.

3.3.2.4  Electric Power-Assisted Bicycle (TRRL)

This document was an example of some of the work carried out at TRRL into EAPCs. The report is a summary of a small scale field study conducted with the aim of assessing the user’s impressions of motor-assist. This study appears to focus on how well the motor and gear combination performs. As part of the study subjects were asked if they had any difficulty “manhandling the cycle” in-between routes when they were asked to lift the cycle up a kerb or to put it on its stand. This could show that the strength required moving an EAPC was a concern of researchers at TRRL at this time.

3.3.3  Summary

It was found that the lower age limit of EAPC legislation was set because 14 years old was the age of legal responsibility. The limit was set by parliament as opposed to DoT, as it would allow local authorities to prosecute the rider of an EAPC if they broke the law. It was also mentioned that 14 years old was also considered an appropriate age when “children can exercise a measure of judgement and skill”, showing that it was recognised that an EAPC would need to be ridden responsibly. This means that while safety considerations were likely to have been investigated at the DoT, the reason for the limit was based on legal reasons rather than safety.

It was found from the documents in the DfT archives that there were several possible reasons for the mass limit. Whether any of these concerns was a primary reason for the limit could not be confirmed. One of the recurring themes, however, was to ensure that EAPCs retained the characteristics of a bicycle as far as possible for both safety and legislative reasons.

There were concerns about the centre of gravity height of EAPCs, that the addition of batteries and motors could raise this high enough to have an effect on stability. The mass limit in this case would not necessarily regulate centre of gravity height itself, but it would limit the effects of a high centre of gravity on the stability of an EAPC.
It was also suggested that an EAPC of increased mass could increase the consequences of an accident to a extent that third party insurance would be required. This shows that there was some consideration that an EAPC of increased mass could be dangerous in an impact situation for not only the rider.

The reason for a mass limit most often mentioned in these files of documents was to limit the performance of the cycle from a battery capacity point of view. Before the power limit was finalised there were concerns that a manufacturer may increase power output while retaining range by adding many batteries. When the regulations were drafted batteries had relatively low energy density, and therefore the amount of power they could provide was limited. This meant that if a manufacturer were to add more batteries in order to increase the range or motor performance of an EAPC, it would increase the mass considerably. Since the majority of the extra weight of an EAPC was the addition of batteries, it was suggested that an overall mass limit would be a good way of limiting battery capacity and therefore performance of an EAPC.

3.4 Summary

No documentation regarding the EAPC regulations was found in the TRL archives. This led to the search of and a visit to the National Archives, which in turn led to a visit to the DfT Archives. The National Archives held three files of documents which were considered likely to contain information relevant to the mass limit of EAPCs. A further four files were selected from the DfT Archives for viewing. The documents from these files were reviewed for information relevant to the mass limit. The files from the National Archives and the DfT both yielded relevant documents.

The age limit was found to be a decision made in parliament to coincide with the age of legal responsibility (14 years old). This indicates that the lower age limit for riding an EAPC was primarily a legal concern rather than a safety concern, and probably not linked to the increased mass of an EAPC. While age was not a factor in the mass limit of the original regulations, it is still a factor to consider in terms of removing the mass limit entirely.

One of the recurring themes of the documents was the aim of EAPCs retaining the characteristics of a bicycle as far as possible. This was from both a performance and handling point of view as well as legislative. It was clear that some of the organisations involved in drafting the regulations were concerned by the speeds achievable by EAPCs as well as the effect of additional mass.

The main aim while drafting the regulations was to ensure that EAPCs were suitable for exemption from the Road Traffic Act. One of the important issues raised in this context was that the mass of EAPCs should be restricted as to limit the potential damage and injury which could be caused in the event of an accident so that third party insurance remained non-compulsory. This shows that consideration was given not only to the rider of an EAPC in drafting the regulations but other road users such as pedestrians also. It is clear that an EAPC of increased mass could have an increased potential for damage and injury in an accident than a regular bicycle, and as such is an important factor to consider in the context of deregulation.

It was identified by several of the organisations involved in the original drafting of the regulations (TRRL, Lucas and Raleigh) that the position of the centre of gravity is an important factor in vehicle handling in addition to overall mass. It appears that it was decided at some stage that both a centre of gravity height restriction would be hard to enforce (especially on add-on kits) and also that the effect of centre of gravity height on handling would be limited by a mass limit. While the first point remains true, the removal of the mass limit could place a greater importance on the position of the centre of gravity of an EAPC in order to ensure safe handling characteristics.
A concern brought up relatively frequently within the documents was the power output of EAPCs. Before the output limit was finalised the mass limit was suggested as a way of limiting EAPC performance. A greater battery capacity would increase the power output an EAPC would be capable of for a given range. Batteries at the time were of relatively low energy density, and so the amount of battery power available for a given weight was relatively low. The mass limit was suggested in some documents as a way of limiting battery capacity and therefore the scope for increasing EAPC performance. Given that there was a top speed and power output limit in the final legislation this shows that another factor was considered important in order to retain the mass limit. This concern about the performance is less relevant to the possible alignment with European regulations since modern batteries are of a much greater energy density than before and the proposed regulations also include top speed and power output limits.

Since there was no exact reason for the mass limit discovered, information likely to be relevant to the removal of such a limit has been given in section 4. While the age limit was ruled out as a factor in the mass limit of the original regulations, it could still be an important safety factor if the mass limit were removed and as such has been included as part of section 4.
4 Other information

Since no definite reasons behind the mass limit were discovered in the search for previous documentation, a review of information likely to be pertinent to the mass limit specification has also been collated.

4.1 Legislation in other countries

The following sections contain short reviews of the regulations regarding EAPCs in use in selected countries outside of the UK and Europe. Particular attention has been paid as to whether or not a mass limit is regulated in each of the regions.

4.1.1 USA

In the USA a “low-speed electric bicycle” is defined as:

"a two or three wheeled vehicle with fully operable pedals and an electric motor of less than 750 watts (1 hp), whose maximum speed on a paved level surface, when powered solely by such a motor while ridden by an operator who weighs 170 pounds is less than 20 mph.” (CPSC, 2003).

There is no direct requirement regarding a mass limit in the US regulations. While these national requirements classify the general requirements of a “low-speed electric bicycle”, it is up to each state to define both their place within traffic law and any additional requirements that are considered necessary.

4.1.2 Canada

In Canada the main technical requirements for classification as a “power-assisted bicycle” are as follows (Transport Canada, 2001):

- Continuous power rating of less than 500 watts
- Maximum assisted speed of 32 km/h
- Motor must not engage below 3 km/h
- Must be pedalled to engage motor-assistance

As can be seen above there is no mass limit stipulated in Canadian national requirements for power-assisted bicycles.

In a similar fashion to legislation in the USA, while these national requirements define what constitutes a power-assisted bicycle it is up to local authorities to define the rules for their use on the road.

The region of Alberta within Canada has a 35 kg mass limit in addition to the national requirements; this requirement was in force before the national regulations were brought into use. The Alberta Transportation Department is planning to remove the mass limit in early 2009 and fully adopt Transport Canada’s definition of a power-assisted pedal cycle. (Alberta Transportation 2008, pers. comm. 24 October).

4.1.3 Japan

In Japan the main technical requirements listed for electric bicycles are:

- Maximum assisted speed of 24 km/h
- Power assist ratio (input:assist) must be under 1:1 at 15 km/h or lower, then gradually reduce at speeds between 15 and 24 km/h
There are no requirements for motor or battery output, since the assist ratio and maximum assisted speed are both defined.

There is no mass limit requirement.

This information was taken from “Regulations on Electric Bicycles in Japan” (Yamaha, 2001).

4.1.4 China

In China the main technical requirements for electric bicycles are:

- Continuous power rating of less than 240 watts
- Maximum assisted speed of 20 km/h
- Mass of less than 40 kg

This information was taken from Standardization Administration of the People's Republic of China (SAC) GB17761-1999 (1999).

As can be seen above, there is a 40 kg mass limit for electric bicycles in China.

4.2 Strength of riders

An increase in the mass of EAPCs could increase the physical strength required to pedal, steer, support and brake while riding. This could lead riders with lower than average strength to struggle to keep control of the cycle, which is a safety risk.

The youngest age at which an EAPC can be ridden in the UK is at 14 years old, and the oldest riders are likely to be elderly. These are the two likely groups of users who are expected to have physical strength at the lower end of the spectrum. For this reason anthropometric data for the strengths of 14 year olds and the elderly were considered in comparison to the average adult. If increased mass of an EAPC would result in a significant rise in the strength required during typical riding then this is a cause for concern.

4.2.1 Strength requirements

Despite the inherent simplicity of the bicycle as a machine, the way in which it is ridden is deceptively complex. High-speed cornering, for example is achieved mainly by leaning rather than simply turning the handlebars, which (counter-intuitively) must be steered the opposite direction of the intended turn in order to provoke a lean. The lean clearly requires the action of more muscles than just of the arms to turn the handlebars in order to negotiate a turn. This is true of many actions required to ride a bicycle.

This makes the physical demands of bicycle quite difficult to quantify. Some actions such as using the brake levers can easily be approximated to common actions which have been tested in anthropometric studies, but others are more difficult. The following section contains appropriate anthropometric data which approximates some of the actions required to successfully ride a bicycle.

4.2.2 Anthropometric data

All of the strength data was taken from the DTi publications Adult Data, Older Adult Data and Child Data.
4.2.2.1 Grip strength

The British Standard for bicycle safety requirements (BS6102-1, 1992) specifies a handgrip force of 180N in part 23.5 of the test specification. This could be taken as the requirement to emergency stop an average regular bicycle, since this part of the BS testing is designed to assess stopping distances.

The motion required to use the brakes on a bicycle can be approximated to squeezing two bars together. Mean grip strengths from studies by Palizcka (1986) on children, Crosby et al. (1994) on adults and Skelton et al (1994) on older adults are given in Table 1. A comparative percentage difference from the BS handgrip force is also included. The values marked with an asterisk were calculated from values given in kg.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Age range</th>
<th>Sex</th>
<th>Mean strength (N)</th>
<th>Standard deviation (N)</th>
<th>Reduction from adult (%)</th>
<th>Difference from BS6102 test procedure (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child</td>
<td>13</td>
<td>Male</td>
<td>255.1*</td>
<td>-</td>
<td>58.2</td>
<td>41.7</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Female</td>
<td>225.6*</td>
<td>-</td>
<td>37.4</td>
<td>25.3</td>
</tr>
<tr>
<td>Adult</td>
<td>16-63</td>
<td>Male</td>
<td>609.9</td>
<td>-</td>
<td>0</td>
<td>238.8</td>
</tr>
<tr>
<td></td>
<td>16-63</td>
<td>Female</td>
<td>360.4</td>
<td>-</td>
<td>0</td>
<td>100.2</td>
</tr>
<tr>
<td>Older Adult</td>
<td>65-69</td>
<td>Male</td>
<td>458</td>
<td>78</td>
<td>24.9</td>
<td>154.4</td>
</tr>
<tr>
<td></td>
<td>65-69</td>
<td>Female</td>
<td>259</td>
<td>29</td>
<td>28.1</td>
<td>43.9</td>
</tr>
</tbody>
</table>

**Table 1: Mean grip strengths of children, adults and older adults**

4.2.2.2 Push strength

When braking, it is necessary for the rider of a bicycle to brace himself against the handlebars with their arms. This action can be approximated to a pushing force at roughly elbow height. Mean grip strengths from studies by McClelland (1976) on children, Daams (1993) on adults and Vorbij & Steenbekkers (1998) on older adults are given in Table 2.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Age range</th>
<th>Sex</th>
<th>Mean strength (N)</th>
<th>Standard deviation (N)</th>
<th>Reduction from adult (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child</td>
<td>12</td>
<td>Male</td>
<td>540.0</td>
<td>153.2</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Female</td>
<td>420.0</td>
<td>99.8</td>
<td>6.7</td>
</tr>
<tr>
<td>Adult</td>
<td>23 (mean)</td>
<td>Male</td>
<td>698.0</td>
<td>96</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>23 (mean)</td>
<td>Female</td>
<td>450.0</td>
<td>93</td>
<td>0.0</td>
</tr>
<tr>
<td>Older Adult</td>
<td>65-69</td>
<td>Male</td>
<td>409.0</td>
<td>50</td>
<td>41.4</td>
</tr>
<tr>
<td></td>
<td>65-69</td>
<td>Female</td>
<td>250.0</td>
<td>66</td>
<td>44.4</td>
</tr>
</tbody>
</table>

**Table 2: Mean push strengths of children, adults and older adults**

4.2.2.3 Summary

Without any detailed information regarding the strength requirements of riding a bicycle it is difficult to determine with accuracy whether or not the strength of riders would be a safety risk on an EAPC of increased mass. It is also difficult to compare in detail strength data for similar actions from different studies, due to slight variances in test methods, equipment and so on. It is, however, useful to compare the relative strengths of each of the groups in order to gauge whether there is a potential safety risk.
It is clear that both younger people around the age of 14 and older adults in the studies have diminished strengths in movements approximately similar to those required when riding a bicycle in comparison to adults. This confirms that these two groups of people could be more disadvantaged by an EAPC of increased mass than adults assuming there is a large effect on the strength required to ride such a machine.

It is also clear that females of all ages in the studies tend to have less strength in these movements than males of the same age group. This means that a younger or older female is more likely to have problems riding an EAPC of increased mass than a younger or older male.

As can be seen in section 4.2.2.1, adults and older males are comfortably able to provide forces well in excess of what is required in the BS stopping distance test. This is not the case for the other groups. Older females and younger males are only able to provide on average around 40% force in addition to the test spec, and younger females only around 25% more. Not only is it advantageous to be capable of exerting a larger force than required so that over an extended period of time less fatigue is experienced, it is likely that an EAPC of increased mass would increase the amount of force required to brake. This data could indicate that some groups of people could be incapable of providing the force required in the BS brake test on an EAPC of increased mass, which could lead to an increased stopping distance. However, it is not possible to conclusively state without specific testing.

4.3 The effects of mass on stability

4.3.1 Increase of mass

There have been many studies into the dynamic stability of a bicycle. These studies have mainly focused on whether the gyroscopic forces associated with the wheels spinning are responsible for the inherent stability of a bicycle at speed. The physics of bicycle stability are fairly complex, and only recently have detailed and correct mathematical models been developed (Kooijman, 2006). However no studies were found that directly evaluated the effects of additional mass or a change of the position of centre of gravity of the bicycle on bicycle handling. This is mainly due to the mass of the rider being much larger than that of the cycle, which diminishes the importance of the cycle in the total centre of gravity.

There was, however, a small scale study conducted by TRRL (Starks & Lister, 1957) into the manoeuvrability of motor-assisted cycles. A cycling proficiency-style course was laid out, and 7 riders negotiated the course on 12 different cycles, each of which was timed. While not strictly equivalent to modern EAPCs, the results were that the motor-assisted cycles were consistently considered less manoeuvrable around the low-speed course. One of the reasons for this could be the increased mass of a motor-assisted cycle.

4.3.2 Centre of gravity position

The position of the centre of gravity of a two-wheeled vehicle can have an effect on its handling behaviour. As mentioned before, the stability of bicycles is a very complex subject, and as such the exact effect on handling behaviour could only be quantified with a specific study. However, a comparison of centre of gravity heights (including the rider) of regular cycles, EAPCs and EAPCs of increased mass may give an indication of whether the increased mass of the cycle has a significant effect on the overall centre of gravity height.

As the rider of a bicycle is of significantly greater mass than the bicycle itself (e.g. a rider of 80 kg and bicycle of 15 kg are reasonable figures), the height of the centre of gravity of the rider/cycle combination is relatively high. Furthermore, assuming that the
centre of gravity height of the cycle itself does not change, a small increase of mass of the cycle would change the centre of gravity height a relatively small amount. However, a cycle of vastly increased mass could move the overall centre of gravity of the rider/cycle combination down a larger amount.

Table 3 gives an indication of the effects of increased cycle mass on the rider/cycle total and the centre of gravity height for regular bicycles, an EAPC and an EAPC of increased mass. It is shown that a large difference in cycle mass results in a proportionally smaller change in total mass and combined centre of gravity height.

The mass of the rider was taken as 80 kg, the mass of a bicycle was estimated as 15 kg, the EAPC mass was taken as the legal limit of 40 kg and the mass of an EAPC of increased mass was taken as 60 kg. The centre of gravity height for all of the cycles was assumed to remain constant, and was estimated at 0.4 m. The centre of gravity of the rider was also assumed to remain constant at 1.2 m. The method by which the centre of gravity height was calculated is given in Appendix B.1.

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Mass of cycle (kg)</th>
<th>Difference from bicycle mass (%)</th>
<th>Total mass including rider (kg)</th>
<th>Difference from bicycle total mass (%)</th>
<th>Total CoG height (m)</th>
<th>Difference from bicycle total CoG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>15</td>
<td>0.0</td>
<td>95</td>
<td>0.0</td>
<td>1.07</td>
<td>0.0</td>
</tr>
<tr>
<td>EAPC</td>
<td>40</td>
<td>166.7</td>
<td>120</td>
<td>26.3</td>
<td>0.93</td>
<td>13.1</td>
</tr>
<tr>
<td>EAPC (Increased mass)</td>
<td>60</td>
<td>300.0</td>
<td>140</td>
<td>47.4</td>
<td>0.86</td>
<td>20.2</td>
</tr>
</tbody>
</table>

Table 3: Comparison of mass and centre of gravity height

It is unlikely that the majority of EAPCs have the same centre of gravity height as a regular bicycle. Batteries and motors are inherently heavy, and so could change the centre of gravity height in comparison to a regular bicycle. Without a mass limit there would be the potential for an EAPC to be designed which is excessively heavy, and has a high centre of gravity. This would be a larger issue when there is no rider on the cycle (e.g. when manoeuvring to park) and so could make the cycle difficult to use for those of lower than average strength.

4.3.3 **Summary**

Since the dynamic stability of a bicycle is a very complex subject, it is not possible to make a broad statement as to whether or not increased mass would affect the stability of an EAPC. It can be mentioned, however, that the position of the centre of gravity is critical to bicycle stability, and that increasing the mass of an EAPC is liable to change the position of the centre of gravity. Without specific tests to evaluate the effect of this it is not possible to say with accuracy whether this would be a safety risk or not.

4.4 **The effects of mass on braking**

It has been documented that the maximum braking deceleration that can be expected to be generated by a regular bicycle without pitching the rider over the handlebars is approximately 0.5g (Wilson, 2004).
4.4.1 Stability

The position of the centre of gravity of a cycle can have a great effect on its stability under hard braking. If it is too high or too far forward then there can be an increased risk of pitching forwards over the handlebars.

The typical maximum deceleration which can be achieved while braking a bicycle without pitching is 0.5g (Wilson, 2004). This is a relatively modest deceleration rate. For example the Highway Code lists the stopping distance (for motor vehicles) from 32km/h as 6m (neglecting thinking time), however assuming a constant deceleration rate of 0.5g a bicycle travelling at this speed would stop after 8m.

There is one case listed in the On The Spot (OTS) database (Cuerden, 2004) of a cyclist ‘going over the handlebars’ and receiving serious head injuries (AIS 2 or greater).

As mentioned in section 4.3.2, it is likely that an EAPC of increased mass would in fact reduce the overall centre of gravity height of a rider/cycle combination in comparison to that of a regular bicycle or EAPC under current regulations. This could be beneficial under hard braking (assuming the braking system is adequate) since it would reduce the likelihood of the rider being pitched over the handlebars. However as also mentioned in section 4.3.2 there is the possibility that a badly designed EAPC could have both increased mass and centre of gravity height, which under heavy braking would make the cycle less stable and more prone to pitching the rider over the handlebars.

The stability of a bicycle braking can be modelled on a very simple level by considering the moments created by the brake force at the centre of gravity position (Wilson, 2004). The centre of gravity positions calculated in section 4.3.2 were used in conjunction with the equations given by Wilson to estimate both the reaction forces at the wheels at 0.5 g deceleration (typical limit of heavy braking for a bicycle) and to estimate the likely maximum deceleration of each cycle assuming that the brakes and tyres were good enough to sustain such a deceleration, and that the bicycle is braked in a perfectly straight line. The calculations are given in Appendix B.

Table 4 shows that there are increased forces associated with braking heavily on a cycle of increased mass. However, the distribution of force is improved considerably by the effect of the increased mass of the cycle on the centre of gravity height, meaning that in these circumstances the cycles of increased mass would be less likely to pitch the rider forwards over the handlebars.

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Force over rear wheel (N)</th>
<th>Force over front wheel (N)</th>
<th>Total force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>59</td>
<td>873</td>
<td>932</td>
</tr>
<tr>
<td>EAPC</td>
<td>157</td>
<td>1020</td>
<td>1177</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>253</td>
<td>1138</td>
<td>1391</td>
</tr>
</tbody>
</table>

*Table 4: Wheel forces at 0.5 g deceleration*

Table 5 shows the possible maximum decelerations which can be generated for each type of cycle without pitching the rider over the handlebars. As can be seen, the increased mass increases the deceleration theoretically possible. The increased mass of the cycle lowers the centre of gravity which allows for a higher maximum deceleration, assuming that the brakes and tyres are capable of producing and sustaining this deceleration.
<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Maximum deceleration (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>0.56</td>
</tr>
<tr>
<td>EAPC</td>
<td>0.64</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Table 5: Maximum theoretical decelerations

It is important to note that the increase of deceleration possible without pitching the rider over the bars is dependent on the ability of the rider to apply enough force to the brakes, for the brakes themselves to apply enough force to the wheels, and that neither tyre loses traction. Without specific testing it cannot be confirmed whether bicycle brakes are capable of this, or if bicycle tyres can sustain increased deceleration on a cycle of increased mass without losing traction.

4.4.2 Distance

As discussed in section 4.2.2.4, an EAPC of increased mass is likely to require greater force applied to the brake levers in order to stop in the same distance. An alternative way of looking at the effects of mass on braking is to assume that the same lever force is applied. In this case it is likely that the stopping distance from the same velocity would increase due to the increased kinetic energy carried by the cycle with extra mass.

Table 6 gives an indication of the increase of stopping distance from simple constant-acceleration equations of motion. The mass of the rider was assumed to be 80 kg, and the speed was taken from BS6102-1:1999 – Specification for safety requirements for bicycles. It should be noted that the minimum stopping distance for this standard is 5.5m. The calculations are shown in Appendix B.

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Mass of cycle (kg)</th>
<th>Stopping distance from 24 km/h (m)</th>
<th>Increase of stopping distance from a regular bicycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>15</td>
<td>4.53</td>
<td>0</td>
</tr>
<tr>
<td>EAPC</td>
<td>40</td>
<td>5.72</td>
<td>26.3</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>60</td>
<td>6.68</td>
<td>47.4</td>
</tr>
</tbody>
</table>

Table 6: Stopping distances

Due to the relatively small mass of a cycle in comparison to the rider it is likely that even at the limit of 40 kg the stopping distance of an EAPC is comparable to that of a bicycle. There are many variables which can affect brake distances such as rider skill and surface friction, so the theoretical stopping distances above are entirely indicative. However, since there have been no studies directly into bicycle or EAPC stopping distances with the addition of mass it is not possible to confirm with accuracy whether or not stopping distances are a safety risk associated with an EAPC of increased mass.

There was a study conducted by TRRL (Kemp, 1953) into the braking performance of motorised bicycles. The motorised bicycles in this study were not electrically powered (rather small-capacity internal combustion engines) and each cycle used different brake systems. Despite this, the report contains some evidence of the increase of brake distance between the pedal and motorised cycles. The discussion section states "the distance required to stop a motorised bicycle is greater than for either a car or pedal..."
cycle and the higher the speed the greater the difference in distance”. This shows the general trend of results were that motorised bicycles took a greater distance to stop, one of the reasons for which could be the increased weight of such machines.

The motorised cycle labelled as “B” in Kemp (1953) was similar to the pedal cycle used in the study in dimensions and also used the same type of brakes, and as such the two can be compared to give a slightly more direct indication of the effect of the increased mass of the motorised cycle. The pedal cycle consistently had lower stopping distances in comparison to cycle B, especially when braking from a high speed on a dry road. Table 4 of the report shows a significant increase of brake distance when comparing the pedal cycle and motorised cycle B. While this study was not directly concerned with the comparison of brake distances between regular bicycles, EAPCs and EAPCs of increased mass, the results are useful in showing that increased mass could be a concern in terms of brake distance.

While it is advantageous from a performance point of view to have a shorter braking distance, it is also not known what the effect of stopping distance is on the likelihood of having an accident for bicycles.

4.4.3 Wear

A cycle of increased mass will have more kinetic energy at a given speed than that of a regular bicycle. This would require the brakes of an EAPC to dissipate more energy in the same braking manoeuvre as that of a regular cycle.

Regular bicycle brakes were considered adequate in the drafting of the 1983 EAPC regulations. This implies that experts were confident that an EAPC of 40 kg would not increase the wear rate of brake consumables to a dangerous extent. This could not be confirmed in the case of an EAPC of increased mass without specific testing.

4.4.4 Wet braking

The previous sections all assume a dry surface, and that neither tyre loses grip during braking. However, when it is wet there is much less grip available on the road surface, which means that it is easier to exceed the grip level.

This would mean that in straight-line braking, the front wheel would be more likely to skid rather than pitch the bicycle forwards, and that the front wheel grip would be the limiting factor. In this situation (without the risk of pitching) the increased mass would be a disadvantage to the EAPC, since (assuming the rider is able to modulate the brakes so that the front wheel does not skid) the level of deceleration achievable would be lower. If the front wheel were to skid then an EAPC could also be at a disadvantage since the increased weight could exacerbate the instability.

This would also mean that if the brakes are used while the cycle is leaned (i.e. while cornering) that it is more likely to slide out in the wet. This is not much of an issue under light braking in the dry since the limit of grip is far higher than the wet. An EAPC of increased mass could be more susceptible to this type of instability.

4.4.5 Summary

An EAPC of increased mass has the potential to increase both stopping distance and wear rate of the braking system if a regular bicycle system is to be used. The difference between an EAPC of 40 kg and a regular bicycle is likely to be negligible; however, this may not be the case for an EAPC of increased mass. This could only be confirmed with specific testing.

An EAPC of increased mass has the potential to increase the stability of a cycle under hard braking under very specific conditions, when braking straight in the dry and
assuming the brakes are capable of decelerating an EAPC of increased mass at the same rate as a regular bicycle. It is possible that the increased mass could do the opposite when braking while leaned or in a turn, and make the cycle more unstable. Once again this could only be established with specific testing.

4.5 The effects of mass on tyres

An EAPC of increased mass is likely to increase demands on the tyres in two ways: through increased mechanical loading and the increased heat transferred to the tyre from sustained braking on cycles with rim brakes (e.g. down hills).

4.5.1 Mechanical loading

Increased mechanical loading could be caused by increased mass. For example the loads experienced by the sidewall could increase when turning or braking, and also the forces at the contact patch would be higher. The increased mechanical loads experienced by the tyres of an EAPC of increased mass could potentially lead to a faster wear rate.

4.5.2 Temperatures

The increased mass could increase rim and therefore tyre temperatures during sustained braking. In order to maintain a constant speed down a hill, a brake force must be applied to counter the force due to gravity. The force of gravity down the hill is proportional to the mass of the bicycle and rider, which means that a rider/cycle of increased mass must use a greater brake force to maintain the same speed as a rider/cycle of lesser mass. This would result in an increase of heat generated by the brakes, which could increase the amount of heat transferred to the tyres.

4.5.3 Summary

Again, due to the relatively low mass of an EAPC in comparison to the rider with the current 40 kg mass limit it is likely that the increase of demands on the tyres of such a vehicle are negligible in comparison to a regular bicycle. It is not possible to say for certain whether or not an EAPC of increased mass would exceed the limits of regular tyres in terms of loading or increased temperature without testing.

4.6 Is the mass self-limiting?

It was found in the National Archives search that one of the chief concerns of the DfT regarding EAPCs was that they handle and perform as close to regular bicycles as possible; this is also likely to be desirable to the consumer. If an EAPC is too heavy to be pedalled without assistance or is difficult to manoeuvre at low speed or when parking then the advantages of such a machine against a small moped are diminished.

Given that European EAPC regulations include a power and speed limit, it may be that the mass of EAPCs is governed by the performance expectations of consumers. As the top speed is limited, the power limit mostly restricts acceleration (and assistance to the rider) assuming that the desired range is constant. One way in which to provide the most acceleration allowable under the regulations is to design an EAPC with as low mass as possible, which could encourage manufacturers to design EAPCs of a reasonable mass even if the mass limit was removed.

One of the concerns of the DfT found in one of the documents in the National Archives search (section 3.2) was that a manufacturer may be inclined to add a large number of
batteries to a cycle in order to increase its range. This would increase the mass of the
EAPC considerably. This is less of an issue nowadays due to the advance of battery
technology. Modern batteries achieve a much greater energy density, which would allow
a smaller (and lighter) battery to provide the same range as before. This makes it much
more likely that the cost of batteries to increase the range of an EAPC could be the
limiting factor rather than a large increase in mass.

4.7 Insurance requirements

As found in section 3.3.1.2, one of the objectives of EAPC regulations was to ensure that
EAPCs would not be significantly more dangerous than bicycles in an impact. Table 7
gives a comparison of the kinetic energy of a bicycle, EAPC and EAPC of increased mass.

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Mass of cycle (kg)</th>
<th>Kinetic energy at a speed of 15 mph (6.70 m/s) - KJ</th>
<th>Increase of stopping distance in comparison to a bicycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>15</td>
<td>2.02</td>
<td>0</td>
</tr>
<tr>
<td>EAPC</td>
<td>40</td>
<td>2.59</td>
<td>28</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>75</td>
<td>3.37</td>
<td>67</td>
</tr>
</tbody>
</table>

Table 7: Potential impact energy

As can be seen, the increase of mass means that the cycle has an increased level of
kinetic energy at the same velocity. This could have implications in a collision since this
energy must be dissipated, which could lead to more serious damage caused either to
the rider or a third party. It could be argued that if the likely consequences of a collision
with a heavier cycle are significantly greater than that of a bicycle, third party insurance
should be mandatory. As was found in the literature search, this was a concern whilst
drafting the original EAPC regulations and is still valid today.

4.8 Summary

The legislation of several countries outside of the UK and Europe were reviewed. It was
found that China and some parts of Canada enforce a mass limit in EAPC regulations.
The US and Japan, however, do not stipulate a mass limit.

It is possible that the removal of the mass limit on EAPCs could lead to cycles designed
with weights are well in excess of a regular bicycle. This could mean that the strength
required to ride such a machine is increased considerably. It is difficult to quantify the
exact physical requirements of riding a bicycle, or indeed an EAPC of increased mass
without a specific study. However, a number of anthropometric studies were identified
which contained strength data of actions likely to be similar to those used while riding a
bicycle, and results relevant to child, adult and older adult age groups were reviewed. It
was found that both the younger and older groups of people have lower strengths than
adults in all of the actions specified. It was not possible to give advice as to whether
their strength level would be a safety risk when riding an EAPC of increased mass.

The stability of a bicycle is a very complex subject, and as such it was not possible to
give definite advice on the effects of mass on the handling. It is likely, however, that
the stability of an EAPC may be affected by increased mass, either from the increase of
mass itself or by the change of centre of gravity position. As part of a TRRL study
(Starks & Lister, 1957) of motorised cycles, a small scale experiment into the handling
effects of the increased mass of the motor was conducted. It was found that the
motorised cycles were less manoeuvrable around the tight cycling-proficiency style
course. While this was not directly related to EAPCs of increased mass, it gives an indication that an increase of mass does have a detrimental effect on low-speed stability.

A comparison of centre of gravity heights of bicycles, EAPCs and EAPCs of increased mass was also performed. While the calculations were heavily simplified, they were adequate to give a good indication on the likely effect. It was found that a large increase of mass of an EAPC did not affect the overall centre of gravity of the rider and cycle combination by a proportional amount.

The effects of increased mass on the braking ability of bicycles were also considered. It was found that while the increased mass would increase the force required to stop an EAPC in the same distance from the same speed as a bicycle, the ratio of front to rear wheel reaction forces was likely to be lower. This means that assuming the brakes and tyres are good enough and that the centre of gravity of the cycles were constant, an EAPC of increased mass could be less likely to pitch the rider over the handlebars than a bicycle. This is due to the decreased overall centre of gravity heights calculated before.

A further way in which the effects of increased mass on braking were considered was to calculate the increase of stopping distance if an EAPC of increased mass was braked with the same force as a bicycle in the same conditions. The conditions used were taken from the relevant British Standards (BS6102-1, 1992). It was found that the increase of mass could theoretically increase the braking distance of both an EAPC at the current mass limit and an EAPC of increased mass beyond the maximum distance specified in the standard. The braking calculations performed (for both the stability and distance considerations) were very much simplified, so the real-world effects of mass on braking could not be confirmed without specific testing.

The tyres of an EAPC of increased mass could be loaded to a greater degree than both regular EAPCs and bicycles. Two ways in which this is likely are in mechanical loading and in heat transfer. The mechanical loads experienced by the sidewall could increase when turning or braking, and also the forces at the contact patch would be higher. The increased mechanical loads experienced by the tyres of an EAPC of increased mass could potentially lead to a faster wear rate.

The tyres could also be subjected to a greater heat transfer from rim brakes, especially when maintaining a constant speed down a hill. A greater brake force would be required to maintain the same speed as a lighter cycle, and assuming the same brakes are fitted then this could lead to a larger amount of heat transferred from the rim to the tyre.

It could be the case that the mass of an EAPC is somewhat limited by factors other than the regulated limit itself. A user of an EAPC is likely to want the vehicle to handle as much like a bicycle as possible, and as such would prefer a lighter EAPC which is easy to ride and park. Another likely preference of a user of an EAPC is to get the best performance possible. Since there is a power and speed limit, another way by which a manufacturer may achieve this is by giving their cycle good acceleration. One way of doing this is to reduce the mass of the cycle itself, thereby increasing the power to weight ratio. A concern from the DfT at the time raised in the National Archives search was that without a mass limit a manufacturer of an EAPC may have been tempted to use a large number of batteries to increase the range. This could be less of an issue nowadays, since the development of battery technology has advanced so that much greater energy densities are possible than before. This could mean that the cost of increasing the range could be the limiting factor before a large increase in mass.

No recent accident data was found relating to EAPCs. The most relevant data which could be found in the TRL archives was a small study of motorised bicycle accidents from 1957. The data given in this study was of a very small range of years, and the data was very limited. One of the conclusions of this study was that more older people have accidents on motorised bicycles in comparison to younger people. This could have been because older people have more trouble riding motorised bicycles, possibly due to the increased mass, or that there were simply more older people riding motorised cycles.
The information presented in this section only gives an indication of the likely effects of mass on an EAPC. It has not been possible in most cases to give accurate recommendations regarding the effects of mass because there has been very little previous work conducted on bicycles and EAPCs in general, and the majority of work that has been done has not been regarding the mass of such machines. The only way in which to give reliable information regarding the effects of increasing the mass of an EAPC would be to conduct testing specific to the addition of extra mass to an EAPC.
5 Summary

No documentation regarding the EAPC regulations was found in the TRL archives. This led to the search of and a visit to the National Archives, which in turn led to a visit to the DfT Archives. Both of these visits yielded documents relevant to the mass limit of the EAPC regulations.

The files at the National Archives did not yield the definite reasons behind the mass limit. The mass limit itself appeared to have been introduced as part of ensuring that an EAPC did not perform vastly different to a regular bicycle. This was in terms of performance increased by the electrical assistance, and in terms of the effect of mass on handling, stability, braking ability and tyres. However, it was clear that throughout the investigative process covered by documents that the centre of gravity position was considered an important safety factor in conjunction with overall mass for inclusion into legislation.

It was found that advice was sought from TRRL, Lucas Industries Ltd and T I Raleigh Ltd and all of these organisations appear to have recommended that centre of gravity position was an important consideration for safety in terms of handling and stability. It was also shown to be likely that the reason that a centre of gravity height restriction was not included in EAPC regulations was that it was deemed too difficult to enforce both at the roadside and on manufacturers of add-on kits which convert regular bicycles to EAPCs.

The files from the DfT Archives also did not give a definite reason behind the mass limit. It was, however, discovered that the minimum age limit of 14 years old was included from a legal basis rather than a direct safety concern. In addition to this several possible reasons for the mass limit were discussed in the documents.

The most common reason discussed in the documents found at the DfT was that a mass limit would effectively limit the size of battery, and therefore the motor performance. Without a power limit it was conceived that a manufacturer could add battery capacity to an EAPC in order to either increase the power output or range. This was more of an issue back when the regulations were drafted for two reasons, because no power limit had been set during the discussions and also batteries at the time had a lot lower energy density than now. A battery of the same capacity with a lower energy density than another would be heavier. This meant that battery weight was far more significant in the design of an EAPC, and the mass limit was seen as a way of limiting battery capacity, and therefore performance. This is less of an issue now from a performance point of view since both current regulations and those of Europe both include power limits. It is also less of an issue now as far as weight goes because batteries currently available have a greater energy density than envisaged when the regulations were drafted.

The height of the centre of gravity was also discussed with reference to the stability of an EAPC in terms of the mass limit. It was considered likely that the centre of gravity height of an EAPC could be higher than a bicycle due to the addition of the batteries and motors, and this could have an effect on the stability. While no centre of gravity height limits were put in place, the mass limit was mentioned as a way of controlling centre of gravity height. This would be because the limited additional mass would limit the effects of an extraordinarily high centre of gravity.

The mass limit was also suggested as a way of limiting the extra damage an EAPC could produce in an accident. The limit was considered to ensure that the result of an accident of an EAPC did not cause sufficient damage to other road users or pedestrians to require third party insurance.

Since no definite reason behind the mass limit was found in both the National and DfT Archives, information likely to be pertinent to the mass limit was also collated.
The legislation of several countries outside of the UK and Europe were reviewed. It was found that China and some parts of Canada enforce a mass limit in EAPC regulations. The US and Japan, however, do not stipulate a mass limit.

It is possible that the removal of the mass limit on EAPCs could lead cycles designed with weights are well in excess of a regular bicycle. This could mean that the strength required to ride such a machine is increased considerably. It is difficult to quantify the exact physical requirements of riding a bicycle, or indeed an EAPC of increased mass without a specific study. However, a number of anthropometric studies were identified which contained strength data of actions likely to be similar to those used while riding a bicycle, and results relevant to younger, adult and older adult age groups were reviewed. It was found that both the younger and older groups of people have lower strengths than adults in all of the actions specified. It was not possible to give advice as to whether their strength level would be a safety risk when riding an EAPC of increased mass.

The stability of a bicycle is a very complex subject, and as such it was not possible to give definite advice on the effects of mass on the handling. It is likely, however, that the stability of an EAPC may be affected by increased mass, either from the increase of mass itself or by the change of centre of gravity position. As part of a TRRL study (Starks & Lister, 1957) of motorised cycles, a small scale experiment into the handling effects of the increased mass of the motor was conducted. It was found that the motorised cycles were less manoeuvrable around the tight cycling-proficiency style course. While this was not directly related to EAPCs of increased mass, it gives an indication that an increase of mass does have a detrimental effect on low-speed stability.

A comparison of centre of gravity heights of bicycles, EAPCs and EAPCs of increase mass was also performed. While the calculations were heavily simplified, they were adequate to give a good indication on the likely effect. It was found that a large increase of mass of an EAPC did not affect the overall centre of gravity of the rider and cycle combination by a proportional amount.

The effects of increased mass on the braking ability of bicycles were also considered. It was found that while the increased mass would increase the force required to stop an EAPC in the same distance from the same speed as a bicycle, the ratio of front to rear wheel reaction forces was likely to be lower. This means that assuming the brakes and tyres are good enough and that the centre of gravity of the cycles were constant, an EAPC of increased mass could be less likely to pitch the rider over the handlebars than a bicycle. This is due to the decreased overall centre of gravity heights calculated before.

A further way in which the effects of increased mass on braking were considered was to calculate the increase of stopping distance if an EAPC of increased mass was braked with the same force as a bicycle in the same conditions. The conditions used were taken from the relevant British Standards (BS6102-1, 1992). It was found that the increase of mass could theoretically increase the braking distance of both an EAPC at the current mass limit and an EAPC of increased mass beyond the maximum distance specified in the standard. The braking calculations performed (for both the stability and distance considerations) were very much simplified, so the real-world effects of mass on braking could not be confirmed without specific testing.

The tyres of an EAPC of increased mass could be loaded to a greater degree than both regular EAPCs and bicycles. Two ways in which this is likely are in mechanical loading and in heat transfer. The mechanical loads experienced by the sidewall could increase when turning or braking, and also the forces at the contact patch would be higher. The increased mechanical loads experienced by the tyres of an EAPC of increased mass could potentially lead to a faster wear rate.

The tyres could also be subjected to a greater heat transfer from rim brakes, especially when maintaining a constant speed down a hill. A greater brake force would be required...
to maintain the same speed as a lighter cycle, and assuming the same brakes are fitted then this could lead to a larger amount of heat transferred from the rim to the tyre.

It could be the case that the mass of an EAPC is somewhat limited by factors other than the regulated limit itself. A user of an EAPC is likely to want the vehicle to handle as much like a bicycle as possible, and as such would prefer a lighter EAPC which is easy to ride and park. Another likely preference of a user of an EAPC is to get the best performance possible. Since there is a power and speed limit, another way by which a manufacturer may achieve this is by giving their cycle good acceleration. One way by doing this is to reduce the mass of the cycle itself, increasing the power to weight ratio. A concern from the DfT at the time raised in the National Archives search was that without a mass limit a manufacturer of an EAPC may have been tempted to use a large number of batteries to increase the range. This could be less of an issue nowadays, since the development of battery technology has advanced so that much greater energy densities are possible than before. This could mean that the cost of increasing the range could be the limiting factor before a large increase in mass.

No recent accident data was found relating to EAPCs. The most relevant data which could be found in the TRL archives was a small study of motorised bicycle accidents from 1957. The data given in this study was of a very small range of years, and the data was very limited. One of the conclusions of this study was that more older people have accidents on motorised bicycles in comparison to younger people. This could have been because older people have more trouble riding motorised bicycles, possibly due to the increased mass or that there were simply more older people riding them.

This information presented only gives an indication of the likely effects of mass on an EAPC. It has not been possible in most cases to give accurate recommendations regarding the effects of mass because there has been very little previous work conducted on bicycles and EAPCs in general, and the majority of work that has been done has not been regarding the mass of such machines. The only way in which to give reliable information regarding the effects of increasing the mass of an EAPC would be to conduct testing specific to the addition of extra mass to an EAPC.
6 Conclusions and Recommendations

6.1 Conclusions

No definite reason for the mass limit included in the 1983 EAPC regulations were found in the TRL, National Archives and DfT Archives. The main reasons mentioned in documents found were, however:

- That EAPCs were to perform and handle in as similar fashion to regular bicycles as possible, and that the mass limit would help achieve this
- The Centre of gravity height should be controlled, however this would be difficult to apply at the roadside and to conversion kits so a mass limit would help reduce the effects of a poorly designed EAPC
- That a mass limit would help to limit the capacity of batteries fitted, and therefore keep the motor performance of the EAPC similar to that of a bicycle
- The mass limit would keep the consequences of an accident of an EAPC to a similar level as a bicycle (and therefore not require insurance)

In addition to this, it was found that the lower age limit of 14 years old was mainly to do with the age of criminal responsibility, rather than a safety concern.

Since no definite reason for the mass limit was found, the following points could be important considerations if the mass limit were to be removed:

- The strength required to ride an EAPC of increased mass could be a safety concern for both younger and older users
- The additional mass may have an effect on both the dynamic stability and centre of gravity of the cycle
- Brake distance may be increased by the additional mass assuming the same brake force is applied
- The increased mass has the potential to increase longitudinal stability under hard braking
- The tyres of an EAPC of increased mass are likely to experience greater mechanical loading and also greater heat transfer
- It is possible that the mass of an EAPC could be governed by consumer requirements even if the mass limit were removed
- There have been no recent studies into accidents involving EAPCs
- Need for insurance / greater potential for damage in a collision
- Increase component wear (brakes)

6.2 Recommendations

Further consideration of factors identified in this initial report is required before any decisions on removing the GB EAPC weight limit are reached.
Acknowledgements

The work described in this report was carried out in the Vehicle Safety and Engineering Division of the Transport Research Laboratory. The authors are grateful to David Hynd who carried out the technical review and auditing of this report.

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Appendix A  National and DfT Archive Documents

Scans of the original documents are given in separate .pdf files.
Appendix B  Calculations

B.1 Centre of gravity calculations
The combined centre of gravity position of a rider and cycle can be estimated from the approximate centre of gravity position and mass of the rider and of the cycle. This is done by averaging the positions, weighted by the masses of the rider and cycle.

\[
y_{\text{combined}} = \frac{(m_{\text{rider}} \times y_{\text{rider}}) + (m_{\text{cycle}} \times y_{\text{cycle}})}{(m_{\text{rider}} + m_{\text{cycle}})} \quad \text{Equation 1}
\]

where \( y \) = centre of gravity height (m) and \( m \) = mass (kg).

For simplicity the cycle and rider for all of the cycles were assumed to have a horizontal centre of gravity position of 0.4m, hence the combined horizontal position remains 0.4m.

Example calculation:
Centre of gravity of a regular bicycle

\[
y_{\text{combined}} = \frac{(m_{\text{rider}} \times y_{\text{rider}}) + (m_{\text{cycle}} \times y_{\text{cycle}})}{(m_{\text{rider}} + m_{\text{cycle}})}
\]

\[
y_{\text{combined}} = \frac{(80 \times 1.2) + (15 \times 0.4)}{(80 + 15)}
\]

\[
y_{\text{combined}} = 1.07 \text{m}
\]

B.1.1 Table of values used

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>CoG height cycle (m)</th>
<th>Mass cycle (kg)</th>
<th>CoG height rider (m)</th>
<th>Mass rider (kg)</th>
<th>Combined CoG height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>0.4</td>
<td>15</td>
<td>1.2</td>
<td>80</td>
<td>1.07</td>
</tr>
<tr>
<td>EAPC</td>
<td>0.4</td>
<td>40</td>
<td>1.2</td>
<td>80</td>
<td>0.93</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>0.4</td>
<td>60</td>
<td>1.2</td>
<td>80</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Table 8: Values used in centre of gravity calculations

B.2 Wheel force calculations
Figure 1: Configuration specified for braking calculations (reproduced from Wilson, 2004)

The method by which the reaction forces at the wheels are calculated is by taking moments about point 2 in Figure 1.

\[ F_{yF} \times w = mg \times CG_x + b \times CG_y \]

**B.2.1 Wheel forces at 0.5 g**

Wheel forces at 0.5 g deceleration

Parameters:

\[ m = 95 \text{ kg}, \ g = 9.81 \text{m/s}^2, \ CG_x = 0.4 \text{ m}, \ CG_y = 1.07 \text{ m}, \ w = 1.0 \text{ m} \]

Calculations (for a regular bicycle):

Total weight force

\[ mg = 95 \times 9.81 = 931.95N \]

Brake force at 0.5 g deceleration

\[ b = 95 \times (0.5 \times 9.81) = 465.98N \]

Front wheel reaction force

\[ F_{yF} = \frac{(mg \times CG_x) + (b \times CG_y)}{w} \]
The rear wheel force is simply the total force minus the force on the front wheel.

\[ F_{yR} = mg - F_{yF} \]
\[ = 931.95 - 871.37 \]
\[ F_{yR} = 60.58N \]

**B.2.2 Maximum deceleration without pitching**

Given that the cycle is likely to pitch when the force on the rear wheel is below zero (i.e. there is no weight on the rear wheel) it is possible to calculate the maximum theoretical deceleration achievable by a cycle. This is done by setting the rear wheel reaction force to zero, and take moments about point 3 in Figure 1.

\[ mg \times (w - CG_x) = b \times CG_y \]
\[ mg \times (w - CG_x) = m \times (a \times g) \times CG_y \]
\[ \therefore a = \frac{mg \times (w - CG_x)}{mg \times CG_y} \]
\[ a = \frac{(w - CG_x)}{CG_y} \] Equation 2

As can be seen by \( a = \frac{(w - CG_x)}{CG_y} \) Equation 2, the maximum deceleration possible is dependant on the position of the centre of gravity and the wheelbase of the cycle. It is clear that a lower centre of gravity height results in a larger deceleration achievable without pitching.

Example calculation using values of a regular bicycle:

\[ a = \frac{(w - CG_x)}{CG_y} \]
\[ a = \frac{(1.0 - 0.4)}{1.07} \]
\[ a = 0.56g \]

**B.2.3 Table of values used**
### B.3 Brake distance calculations

The brake distances were calculated in a very simple fashion. The overall brake force required to decelerate a regular bicycle at a rate of 0.5 g was calculated. This figure was then used to calculate the rate of deceleration which would occur if this same brake force were applied to cycles of increased mass (i.e. EAPCs and EAPCs of increased mass). Finally brake distances for a speed of 24 km/h were estimated for all 3 cycles using simple constant acceleration equations.

#### B.3.1 Brake force (regular bicycle)

\[ F = ma \]
\[ = 95 \times (0.5 \times 9.81) \]
\[ F = 465.98N \]

#### B.3.2 Deceleration of EAPCs

\[ F = ma \]
\[ \therefore a = \frac{F}{m} \]
\[ a = \frac{465.98}{m} \]

As an example, the deceleration of a regular EAPC given the same brake force as a bicycle is:

\[ a = \frac{465.98}{120} \]
\[ = 3.88 m/s^2 \]
\[ = 0.40 g \]

---

Table 9: Values used in wheel force calculations

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Total mass m (kg)</th>
<th>Gravity g (m/s^2)</th>
<th>CoG horizontal CGx (m)</th>
<th>CoG vertical CGy (m)</th>
<th>Wheelbase w (m)</th>
<th>Deceleration (wheel force) (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>95</td>
<td>9.81</td>
<td>0.4</td>
<td>1.07</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>EAPC</td>
<td>120</td>
<td>9.81</td>
<td>0.4</td>
<td>0.93</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>140</td>
<td>9.81</td>
<td>0.4</td>
<td>0.86</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>
**B.3.3 Brake distances**

As mentioned before, the brake distances were estimated using simple constant acceleration equations of motion.

\[ s = \text{distance (m)} \]
\[ u = \text{initial velocity (m/s)} \]
\[ v = \text{end velocity (m/s)} \]
\[ a = \text{acceleration (m/s}^2) \]
\[ t = \text{time (s)} \]

First the time taken to complete braking was calculated:

\[ v = u + at \]
\[ \therefore t = \frac{v - u}{a} \]

\[ v = 0 \text{ m/s, } u = 6.67 \text{ m/s (24km/h)} \]

As an example, the time taken to brake a regular EAPC:

\[ t = \frac{v - u}{a} \]
\[ t = \frac{(0 - 6.67)}{(-0.40 \times 9.81)} \]
\[ t = 1.72s \]

From this, the stopping distance can be estimated:

\[ s = \frac{(u + v)t}{2} \]

As an example, the distance to brake a regular EAPC:

\[ s = \frac{(u + v)t}{2} \]
\[ = \frac{(6.67 + 0) \times 1.72}{2} \]
\[ s = 5.72m \]
### B.3.4 Table of values used

<table>
<thead>
<tr>
<th>Type of cycle</th>
<th>Total mass m (kg)</th>
<th>Start velocity (m/s)</th>
<th>Deceleration (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>95</td>
<td>6.67</td>
<td>0.5</td>
</tr>
<tr>
<td>EAPC</td>
<td>120</td>
<td>6.67</td>
<td>0.4</td>
</tr>
<tr>
<td>EAPC (increased mass)</td>
<td>140</td>
<td>6.67</td>
<td>0.34</td>
</tr>
</tbody>
</table>

**Table 10: Values used in braking calculations**
Investigation of appropriate mass for electronically assisted pedal cycles

It is understood that the DfT are considering a review of the British legislation regarding EAPCs following the publication of new draft standards being developed by CEN, the European standards body. In undertaking this work it is imperative that potential alterations to current standards are investigated so that safety is not compromised. One such difference is that, unlike British legislation, the draft CEN standard does not include a mass limit.

The information presented only gives an indication of the likely effects of mass on an EAPC. It has not been possible in most cases to give accurate recommendations regarding the effects of mass because there has been very little previous work conducted on bicycles and EAPCs in general. The only way in which to give reliable information regarding the effects of increasing the mass of an EAPC would be to conduct testing specific to the addition of extra mass to an EAPC.

Further consideration of factors identified in this initial report is required before any decisions on removing the GB EAPC weight limit are reached.

Other titles from this subject area

PPR490 The acoustic durability of timber noise barriers on England’s strategic road network. P A Morgan. 2010
PPR485 The performance of quieter surfaces over time. M Muirhead, L Morris and R E Stait. 2010
PPR394 An examination of the monetised benefit of proposed changes to type approved noise limits for tyres. M Muirhead, P G Abbott and M Burdett. 2009
PPR270 Scoping study on the potential for instantaneous emission modelling: summary report. T J Barlow, P G Boulter and I S McCrae. 2007