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A review of the design review process for fairground rides

Prepared by **Atkins**
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A review of the design review process for fairground rides

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This report reviews the current usage of the 'design review' process in the UK fairground industry. Its influence in assuring the safety of rides has been evaluated, considering background perspectives from normal practice in other industries.

The UK framework and practice for fairground safety has been developed over a number of decades, which includes the involvement of a number of regulatory bodies and other organisations. Various guidance documents and publications are available, and these have been used as the baseline measure of current practice. Liaison has been established with a number of ride owners and design reviewers to confirm how this is applied in practice.

The review has focused on two areas of the design review: the structural integrity of the ride and the risk assessment process. Particular attention has been concentrated on the structural aspects, since operating experience has shown these to be the largest current contributor to significant incidents on fairground rides.

A number of key points and recommendations have been raised throughout this report. The key points arising from this review have been assembled in summary form in the Conclusions of this report with respect to the following aspects of the design review.

- Safety Framework
- Design Review
- Structural Fatigue
- Inspection and Maintenance for Fatigue
- Risk Assessment
- Communication

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

The Amusement Device Safety Council (ADSC) has noted the findings of this report carried and is pleased to record that it has already taken positive measures to effectively address a number of the issues raised in this report including the introduction of revised systems and procedures relating to the production of Design Reviews. The ADSC will continue to monitor and review ways in which safety can be further promoted in conjunction with the HSE.

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1 INTRODUCTION

The UK fairground industry has received a good measure of attention from the HSE and other interested bodies, which is commensurate with its public involvement.

The latest published HSE review of the industry is entitled "Review of Fairground Safety", and was written by HSE Principal Inspector P. Roberts in 2001 (Ref. 1). A number of points arising from this document have been addressed during the following years.

The HSE also provides guidance information for use by the fairground industry. For example, the document entitled "Fairgrounds and Amusement Parks – Guidance on Safe Practice", HSE report HSG 175 (Ref. 2) is a standard UK reference, which is referenced internationally. Information published on its website includes Entertainment Sheet No 5, "Fairgrounds and Amusement Parks" (Ref. 3), and Entertainment Sheet No 8, "The Amusement Devices Inspection Procedures Scheme (ADIPS)" (Ref. 4).

There are several organisations and guilds which exercise an influence over different aspects of the fairground industry in the UK. They involve varying degrees of membership, certification and discipline, and they disseminate guidance on good practice. Examples of these organisations are the Fairgrounds Joint Advisory Committee (JAC) and National Association for Leisure Industry Certification (NAFLIC), amongst others. They contribute to the formation of standards in the UK and internationally, relying on the experience of several well established and leading UK practitioners.

One of the points arising from the 2001 Review of Fairground Safety is that there are some areas where HSE influence is less direct. For example, with rides imported from other countries, buying and selling of used rides, and modifications to rides. This is covered in the UK industry by the requirement to commission a "design review" when these situations are encountered.

This report presents the results of a project to observe how the "design review" process is currently working, and it makes various recommendations. Clearly the findings of this report relate to the fairground industry at the current time.

2 SCOPE AND APPROACH

2.1 AIM OF WORK

The aim of this project has been to take an independent view of the potential for major accidents on fairground rides in the UK, and the influence of the design review in reducing it.

The review is based on the current setup of the fairground industry, and points are raised in this context.

2.2 SCOPE OF REPORT

This report concentrates on major rides, which have the potential for incidents with multiple injuries or even fatalities, as highlighted in the 2001 Review of Fairground Safety. The review has focused on two areas of the design review: the structural integrity of the ride and the risk assessment.

Particular attention has also been given to fatigue of main structure or components, which operating experience has shown to be the largest current contributors to the potential for major incidents. Fatigue is the main deterioration mechanism of concern, and a whole section of the report deals with this.

This report is not intended to give complete guidance, since much is already available, and good practice already exists in many areas. Rather, it selects particular issues which are judged to be of significant benefit to the current industry approach, in two ways:

- Aspects of good practice that have been observed in some instances, which would be beneficial to reinforce,

- Aspects which might be improved upon.

This report includes perspectives from other industries. Some of these other industries have equipment similar to the fairground industry, and have stringent requirements for safety, because of the possibility of serious injury or fatality.

It intends to assist the design reviewer in achieving current best practice. It is also intended to assist the ride controllers, to enable them to judge the adequacy of design reviews that are performed for them.

It concentrates on fixed rides which are new or imported from other countries. The conclusions, however, potentially cover new rides manufactured within the UK and could also be adapted to cover second hand, modified and travelling rides from the UK or abroad.

2.3 APPROACH

The current state of the fairground industry has been measured by the various current guidance documents and publications used in the fairground industry, as a baseline.

Liaison with various ride owners and design reviewers has been established to confirm how this is applied in practice. A number of rides have also been visited.

2.4 LAYOUT OF REPORT

To ensure the safety of major fairground rides requires a diverse range of aspects to be covered. The design review is no exception. This report divides it into manageable parts, each Section dealing with one selected part. Extended points of detail have been placed in the Appendices.

The main sections are as follows.

Framework for Fairground Safety

This deals with the overall framework into which the design review fits.

Design Review

This deals with doing the design review.

Structural Fatigue Assessment

Fatigue cracking is selected here, since it is the major contributor to significant fairground incidents. The calculation / prediction of fatigue lives are dealt with here.

Inspection for Fatigue Damage

This deals with the inspection requirements that are specified on the basis of the fatigue assessment. It does not deal with the carrying out of the inspections, which are covered elsewhere.

Risk and Safety Assessment

This section gives guidance for doing a risk assessment, within a wider industrial perspective.

Communicating Key Information

Communication between the various specialists involved and the ride controller is vital, ensuring that required actions are completed.

Conclusions

This section assembles the main points and recommendations arising from this work. They are taken from the main part of the report.

3 FRAMEWORK FOR FAIRGROUND SAFETY

This section takes a view of the whole safety management framework within which the design review fits. The obvious aim is to reduce the occurrence of accidents of all types, but especially to reduce the potential for incidents with major injuries or multiple fatalities.

3.1 CURRENT FRAMEWORK

The UK framework and practice for fairground safety has been developed over a number of decades, and this is set to continue, with the ever increasing complexity and scale of rides, and increasing expectations on safety.

A current baseline has been taken from the current HSE published documents.

The definitive UK document is the HSE report HSG 175, "Fairgrounds and Amusement Parks – Guidance on safe practice", 1997 (Ref. 2). A shorter summary is given in Entertainment Sheet No 5 (Ref. 3), which is currently published on the HSE website, and referred to in various other documents. It is also dated 1997.

The current UK framework can be summarised as follows, as laid out in HSG 175 Section A:

- The design of the ride is to be carried out by suitably qualified and experienced designers.
- A design review is required, in which the safety aspects of the design are checked, preferably prior to manufacture. The inspection body has to confirm in writing that the design (whether produced in the UK or from abroad) is sound and that the calculations are correct.
- The extent of the design review that is required depends on the level of risk involved.
- Before operation, the ride has to be assessed for conformity to the design.
- An initial function test is required.
- An operating manual is to be assembled and kept up-to-date. It includes the design review report, with other inspection reports and relevant information.
- Maintenance and daily checks are to be carried out.
- Thorough examination is called for, to enable the inspection body to decide whether the ride may be operated for a specified period of time.
- Supervision and emergency procedures are to be in hand.

There are many other schemes and documents which support good safety practice, including the following examples:

- The Amusement Device Inspection Procedures Scheme (ADIPS). This is a system for ensuring that proper inspections and certification are monitored. It is described in HSE Entertainment Sheet No 8 (Ref. 4).

- Detailed guidance given by NAFLIC. This includes Technical Bulletins, which disseminate information on service experience, problems encountered in practice, and solutions.

- The European design code for fairground rides, prEN 13814 (Ref. 5).

The ADIPS scheme has established standards for the inspection process within the industry. The requirement for annual independent inspections also provides checks on any modifications that can be made to rides. This has made good contributions to the safety of fairground rides.

However, decisions still need to be made on what to inspect, how often, and using what techniques. Manufacturers should provide this information; however, the main check for this is the design review.

In this work, it has been possible to liaise with some of the established UK design review practitioners and some ride owners. Although the extent of liaison has been limited, good practice is evident in many areas, and the current framework does seem to be largely workable. There are some areas that might be improved, and these are raised in this report.

It has not been possible to confirm whether all practitioners in the UK fairground industry follow the same approach as those that have been liaised with. Hence, one of the aims of this report is to reinforce key aspects of good practice which have been observed.

One overall area of slight concern is the large number of guidance documents and sources of information in the fairground industry. These documents are continually being amended and added to. Whilst this is good in principle, it can detract from the main aim of achieving good and consistent safety for fairgrounds. It is hoped that a compact set of more definitive guidance will be achieved in the near future.

3.2 PARTIES INVOLVED

Several parties are often involved in the safe operation of a major fairground ride. The customary descriptions are used here, following and extending the HSG 175 guidance.

Designer, Supplier, Manufacturer, Installer, Importer

Inspection body	This is the appointed organisation which delivers the on-going inspection. By implication, it gives the owner regular reports on the safety of the ride.
Inspector	This is the individual who does the actual inspections – visual and other checks.
Inspector (NDT)	This is the individual who does the detailed Non Destructive testing work on structural and mechanical items.
Inspector (HSE)	This is the HSE staff member who checks on the safety management of the ride
Design reviewer	This is the appointed inspection body which need to establish whether a design is sound and the calculations are comprehensive and correct.

Owner	In some cases this can be only the legal owner, who employs others to manage it. `
Controller	This is the person who, on behalf of the owner, is responsible for managing the safety of the ride. This person can also be the owner.
Ride attendant	This is the person who physically operates the controls, and deals with the people going on the ride. The alternative term "ride operative" can be used.
Operator	This term is not recommended since it can be ambiguously used. It could variously refer to the owner, or the controller, or the ride attendant. For the sake of clearly defining responsibilities, this term is not recommended.

3.3 PURPOSE OF A DESIGN REVIEW

The aim of the design review is to verify the adequacy of the safety of a ride by having an independent review of the ride. But more than this, it also aims to capture aspects in which the fairground industry is known to be potentially vulnerable to.

The latter need arises from the fairly light legislative framework for the fairground industry compared with other industries - which may be appropriate in the context of its diversity and constant change, and the strong role played by various fairground industry organisations. This is discussed in Ref. 1.

Potentially vulnerable points in the current UK fairground industry arise because of:

- Several parties being involved in the production and operation of a major ride,
- Buying and selling of rides, and changes of management
- Importing of rides from outside the UK, and hence outside UK control
- Non-uniformity of design approaches
- Variable quality of manufacture
- Commercial pressures in situations where profit margins are slim
- Modifications to rides

Hence the design review is an important safeguard, provided that it can be done consistently. This report aims to assist in this respect.

3.4 WHEN A DESIGN REVIEW IS NEEDED

HSG 175 is clear about when a design review is needed. In Section C it requires a design review for:

a. a new , newly imported, or second hand ride,
b. any safety-critical modification.

Examples of changes that affect the safety of the ride include the following:

- Physical modifications to safety critical parts.
- Changes to the Inspection Requirements, including changes to required inspection intervals or deferrals or non-completion.
- Changes to the Operating Instructions, or operational restrictions.
- Occurrence of damage or cracking. The inspection requirements need to be re-confirmed or adapted in response to this.
- Unusual loading or incidents on the ride.
- Notice of damage or cracking in other similar applications – e.g. in response to NAFLIC Bulletins. The inspection requirements need to be re-confirmed or adapted in response.
- Service experience. After a suitable time (e.g. after 2 years, 5 years and 10 years, and after the design life) it is suggested that the inspection requirements need to be re-confirmed or adapted.
- Temporarily bringing in a ride to a fairground.

An independent review of any of these changes must be carried out. This means a repeat design review, or at least a partial review. It is necessary to track this process, to ensure that the safety management of the ride is up to date. In practice, it is not always evident that this is always being done, or at least being recorded clearly.

At present, little industry guidance seems to be offered for change control of a design review. For example, Section A Table 1 of HSG 175 gives no suggestions.

It is recommended that a design review is given a specified expiry date, after which it should be revisited. This might be at a proportion of the design life, or after a certain time of operation, especially if experience is being gained with a new type of ride, or a fixed number of years.

It is important to have an efficient change control system, with the minimum paperwork, and clear communication of information. This is discussed further in Section 8.

3.5 RESPONSIBILITIES OF CONTROLLER

The ride controller is appointed by the owner to manage the ride safely. As such, the controller has the ultimate responsibility for the safety of the ride. The controller can also be the owner.

The controller, therefore, carries the risk for the ride. This cannot ultimately be deferred to the designer / reviewer etc. The controller has a duty to be aware of what the risk levels are, and be engaged in actions which keep them low.

In this context, it is essential that the controller has a certain minimum level of knowledge about the ride – e.g. thoroughly know the Operating Manual, understand the basic operating principles of the ride, know the risk levels and what the main contributors are. This requires a certain level of interaction with the designer / reviewer.

The controller is responsible for ensuring that the Operations Manual is maintained well. It is recommended that the most important parts be kept in a single volume, so that the crucial information is kept in a clear and concise manner, and readily accessible. This should include the Operating Instructions, Inspection Requirements, Maintenance Instructions, and all safety summary sheets, with records of change control and actions completed.

It is recommended that bulky supporting information, such as the main design review, detailed inspection records, etc are kept in separate volumes, and referenced from the main volume of the Operations Manual.

In addition, the controller needs to handle the design review process appropriately. For example they would need to:

- have a clear up-to-date summary of the latest review / certification status of the ride

- for changes, to know what areas of the ride need to be reviewed, and to clearly communicate this scope to the reviewer. This scope should not be restricted by budget or timescale considerations. It should be based on ensuring that all safety critical parts are reviewed to current safety standards

- be able to evaluate the competence of reviewers (based on qualifications, track record, thoroughness of previous reviews, etc), and the thoroughness of a review carried out

- provide adequate information for a design review, and ensure that budget or timescale considerations do not compromise the safety of the ride, by applying undue restraints

- discuss with the reviewer the main areas of risk, and what mitigations need to be put in place, and how much ground for confidence there is. It is probably good to partition major incident hazards from the most likely/frequent minor hazards, both of which could be considered as significant risk contributors, but need to be managed differently

- remember the main risk areas in the managing of the ongoing inspection and assurance activities, and keep particular vigilance in these areas

It has also been stated elsewhere that the competence of duty holders (all concerned with the ride, from designer through to controller and attendant) may be an issue that needs to be addressed in the industry (Ref. 6).

It is recommended that purchasers and controllers of a ride place a high priority on through-life costs, including inspection and maintenance, for their planning. This will help in avoiding undue economic pressures arising during the service life. There is the potential for a manufacturer or seller to understate the level of inspection and maintenance, for sales reasons.

We would emphasise the value of keeping and reviewing operational records – by the log book or equivalent. This gives more knowledge of the safety of that particular ride (as well as the generic type), which is influenced by the way it has been used and maintained. This will affect the setting of inspection intervals, and benefits can be gained by showing good records in this respect.

3.6 APPOINTMENT OF DESIGN REVIEWER

The reviewers need to be suitably qualified and experienced for the aspects which they are covering. In practice a reviewer is rarely qualified for all aspects of a complex ride and will usually sub-contract sections to another reviewer. Each reviewer must recognise their own areas of experience and the limitations, and operate within these.

In HSG 175, the design review is stated as a task to be carried out by the "inspection body". For clarity, it is noted here that the design review task is different from the majority of inspection work, being more of a design and assessment function, an area that is normally handled by qualified structural, mechanical, or electrical engineers.

One area of concern that has been observed is the procuring of a partial review, but with a seeming expectation that the review should cover the whole ride. This can be avoided by ensuring that the controller gives a clear specified requirement, and that the reviewer gives a clear statement of the scope of the review that has been done.

3.7 REPORTING OF RESULTS

The prime requirement is that the ride controller has a clear single statement on the adequacy or otherwise of the design of their ride (including the requirements of the operating manual).

It is essential that design reviewers are given scope to clearly state important points that need to be communicated to the controller. This includes:

- State their remit of their review – and restrict it where necessary – and make this evident to the controller – so that a partial review is not mistaken for a full review.
- State any reservations, concerns, or required actions from the design review.
- Communicate what are the main risk areas, and what mitigations have been applied, and what reasons can be given for confidence in safety. This enables the controller to focus on the most important parts.

More detail in given in Section 8.

3.8 FRAMEWORK – KEY POINTS

Key points on the overall Safety Framework are summarised as follows:

- The ride controller is responsible for the risks associated with the ride. The design review process must be managed appropriately. This includes defining clear scopes of work (particularly for partial reviews), providing adequate information, and ensuring that there are not undue pressures (including commercial and timescale) which would hinder the various parties from adequately functioning.
- The design reviewer must be adequately qualified and experienced in the areas which they are working, and should refer out to other parties when they reach their limits.
- The design reviewer should clearly state the scope of their review, the conclusions, any reservations, any required actions, the main risk areas, and the expiry date of the review.

- It is beneficial to have a clear, single statement on the current adequacy of the ride, and any required actions that need to be carried out.

- It is important that the Operations Manual includes all the relevant information in a clear and concise and readily accessible manner. It is suggested that the most important parts be kept in a single volume (including the Operating Instructions, Inspection Requirements, Maintenance Instructions, safety summary sheets, records of change control, and actions completed). More bulky supporting information (such as a full design review report) can be kept in separate volumes, and referenced from the main volume.

- The importance of the Inspection Requirements is emphasised. It is likely that they will be revisited time, and this will require independent review. Any changes or non-completion of inspections of safety critical parts need to be tracked and independently reviewed.

- It is recommended that the Inspection Requirements be reviewed and adapted periodically when additional information becomes available. For example, after any occurrence of damage or unusual incidents, after experience becomes available for similar rides, after specified number of years of operating experience for the ride.

- It is recommended that purchasers of a ride place a high priority on through-life costing and downtimes, including the effects of inspection and maintenance. This will help in avoiding undue commercial and timescale pressures on the controller during operations. There is the potential for a manufacturer or seller to understate the level of inspection and maintenance, for sales reasons.

- It would be beneficial to give more profile to the fact that the design review is likely to be revisited during the life of the ride.

- It would be beneficial to gather the various fairground practice and guidance into a smaller set of more readily accessible references.

4 DESIGN REVIEW

4.1 CONTENTS OF A DESIGN REVIEW

HSG 175 Section 81 gives the following requirements for a design review

- design documents including any safety requirement specification and operating instruction are complete and sufficiently detailed;
- any necessary design review work outside the reviewer's competence has been done by others with relevant competencies;
- assumptions are questioned, particularly those on which any calculations are based;
- any calculations are correct. If computer programs have been used the calculations should be checked using different software;
- the design documents are consistent with appropriate standards, specifications, guidelines and industry practice;
- the extent of the review is appropriate. Some modifications may require only limited review, but a change to the seating capacity, for instance, might require the whole device to be reassessed;
- inspection and maintenance instructions are consistent with design data.

All safety-related aspects of a ride need to be covered. HSG 175 includes mentions the following:

- Risk and safety assessment ;
- Structural integrity;
- Design and operation of any control system;
- Ergonomic design of passenger containment systems;

Further clarification can be given to include the following aspects where appropriate:

- Structural and civil infrastructure
- Mechanical equipment and moving components, including hydraulics and pneumatics
- Electrical equipment and power supplies
- Control and Instrumentation of ride and safety functions
- Man-machine interface and interaction of the ride attendant with ride
- Passenger interaction with ride and passenger containment or restraint.

- Testing, Inspection and Maintenance

Of all these points above, operational experience suggests that the structural aspects cause the most incidents. Section 5 and Section 6 concentrates on this aspect. Furthermore, due to the lack of clarity regarding the use of and scope of risk and safety assessments in the design and design review of fairground rides, Section 8 focuses on the risk and safety process.

4.2 CRITICALITY LEVEL

It would be beneficial to identify a "criticality level" for each ride. This is a normal approach in most industries. It would be based on the potential for major injuries or multiple fatalities. It enables the level of detail for the whole design, manufacture and safety management process to be defined.

Some points relating to this are given in Appendix A. Further work would be required to work these up into useable guidelines.

4.3 LEVEL OF DETAIL REQUIRED

The level of detail required in the design calculations and the design review is a safety-related matter. As such, it needs to depend on the criticality level, the complexity of the ride, and the variability in the calculation methods. It should not be determined by other reasons such as budget or timescale.

It is acknowledged that the cost of a ride is usually indicative of its complexity, and this can be broadly related to the extent of the design review. However, it is not a sufficient indicator on its own, and a separate view from this should be taken, to determine what is an adequate level of detail from a safety point of view.

4.4 COMMERCIAL PRESSURES

In common with many practical situations, commercial considerations have a strong influence on the overall operation of fairground rides. This should not be permitted to influence safety considerations, especially in the context of potential major incidents. Whilst loss of livelihood is not to be under-estimated, loss of life is more important.

This affects the fairground industry more than some others, in situations where profit margins are slim.

Potentially, this could adversely affect the level of detail of the design reviews, and the Inspection Requirements, the reporting of reservations, and the clarity of reporting.

Both the controller and the reviewer should be aware of this potential problem, and be diligent to ensure that this does not occur.

4.5 INFORMATION REQUIRED

The first step in a design review is to ensure that all the necessary documents and information are available. This depends on the criticality level of the ride.

The availability of the necessary documents appears to be an area where the design reviewer can be exposed. The reviewer may need some form of support to enable them to expect adequate information, or if not available, to state a qualification in their summary, or require the information to be re-created (by another party, since the review is intended as an independent check).

The controller must be diligent to ensure that the design reviewer is not under undue pressure at this point, so that they can properly discharge their duties.

A suggested document checklist is given in Appendix B.

4.6 PERFORMING THE DESIGN REVIEW

In addition to the reviewer having all the necessary documents, it is also important to check that the controller of the ride provides all the information that is required to manage the safety of the ride, e.g. Operations Manual, Inspection Requirements, etc. Some reviewers have such standard requirement lists with explanatory notes. The industry may wish to produce an example of an information requirement list that any reviewer could use.

The understanding of the ride operation and the quality of fabrication and condition of the ride are important, and a visit by the reviewer to observe the ride in operation is strongly recommended.

Even with all the required information it is necessary to consider the following points.

i Visit the ride to see its condition and operation.

ii Is it clear how the ride works?

iii What is the standard operating cycle?

iv How much variability in operation is possible – either intended or unintended? Variations in standard loading could come from the following – e.g. weight distribution, out of balance loads/masses, accelerations, heights, rotations, vigour of operation, wind, ground conditions, gyroscopic and centrifugal forces etc.

v Can undesirable operations be physically locked-out? If an action is not prevented then it should be included in strength and fatigue calculations.

vi Is the ride seasonal? What is its frequency of use?

vii What is the age of participants? Control of these aspects could depend on ride risk category.

viii Where physically will the ride be operated? This will affect the ground conditions and wind speed to be assessed.

ix Consider the role of test measurements in confirming accelerations and loadings.

x What is the quality of fabrication? In particular, concentrate on items that undergo cyclic loading and are prone to fatigue. The fatigue life of these components is strongly influenced by the detail design, surface finish and quality of fabrication. Particular attention should be paid to welding. The fatigue life will be very much reduced if the welding quality is below the normal standards for which the design codes are written.

4.7 BALANCE OF RESPONSIBILITY

It is important to set up the design review process such that the right level of work and detail is done.

If the controller is too dominant in this interaction, the reviewer may be under undue pressure such that they are impeded from giving a fair and balanced statement of the risk levels, and from freely discussing any reservations that they might have.

If, on the other hand, the reviewer is too dominant in this interaction, the controller may not be in a position to fully ascertain the real risk levels involved, and the level of thoroughness of the review.

It is recommended that both parties diligently work together to get a good balance in this interaction.

4.8 PRACTICE IN OTHER INDUSTRIES

The HSE Review of Fairground Rides already makes mention of the practice for lifting equipment, as covered by the LOLER and PUWER regulations. Cranes are also a near equivalent to many fairground rides. Other industry practice is as follows.

- In the bridge industry a new design is subject to an independent design review. There are four categories for the review, and the extent of the reviewer's independence increases with category. The categories are set based on the ***size***, ***complexity*** and ***novelty*** of the bridge. [Technical Approval of Highway Structures, BD2/05, August 2005].

- In the pressure vessel industry there are four levels of assessment for different levels of hazard which are based on ***pressure***, pressure x volume (***potential energy***) and ***temperature***. There is a separate group classification for whether the content is ***hazardous*** or not. [Pressure Equipment Directive, Article 3 Technical requirements, Article 9, Classification of pressure equipment and Annex II, Conformity assessment tables].

- In the offshore industry, Safety Critical Elements have to be identified and managed. The Inspection Requirements have different levels of detail for different levels of criticality, and these requirements need to be achieved.

It is more practicable to categorise the criticality of the ride as a whole, and then justify within this the level of details required to assure the safety of different parts. For example, a main structural member may have redundancy and thus require only a modest assessment and inspections, but the attachment components may have no redundancy and thus require a full assessment and inspections.

4.9 DESIGN REVIEW - KEY POINTS

Key points on Design Review are summarised as follows:

- The setting of a criticality level for each ride is recommended, based on the potential for major injuries or multiple fatalities. Some discussion is given in Appendix A of this report.

- The level of detail of a design or assessment should be related to the criticality level and uncertainties, but not to commercial or timescale issues. It would be beneficial if the industry were to set up some standard guidance on this.

- The ride controller and the design reviewer should work together to good interaction and two-way communication of information.

- It is strongly recommended that the reviewer visits the ride to see it in operation. The loading levels, operating cycle, fabrication quality, and condition have a strong influence on the safety performance and fatigue life.

5 STRUCTURAL FATIGUE ASSESSMENT

Structural failures have been the main source of significant fairground incidents. From a set of 200 serious or fatal accidents considered by Fawcett, 2003 (Ref. 6), the biggest cause is structural failures, accounting for a third of these accidents.

The most significant contribution to structural incidents is fatigue. This is evident in the various NAFLIC Technical Bulletins, which give many instances of structural fatigue, both in the main structure (booms, radial arms, etc) and in components (including brake and motion drive components).

Others types of failure can have equally serious consequences, (e.g. hydraulic, electrical, control systems failures, etc), but the number of incidents reported to be caused by these is much lower than the structural aspects. Therefore, these aspects are not pursued further in this report. This section concentrates on structural fatigue.

There is much good guidance on structural design and assessment, (for example, from NAFLIC guidance, and design codes). This report does not aim to repeat that guidance, but rather to highlight areas that have been selected for emphasis or for improvement.

5.1 CONTEXT OF FATIGUE ASSESSMENT

Movement and acceleration are an inherent part of the entertainment experience being provided by fairground rides. So they are inevitably subjected to repeated cyclic loading, and this causes fatigue damage.

Fatigue can be a ‘hidden’ risk, since it is not so obvious to the eye, and it progresses with time, such that it is not usually found by initial test and inspection. It requires careful specialist inspection to detect. By contrast, other degradation mechanisms such as corrosion and wear are more amenable to detection by visual inspection, and various functional and overload tests.

Main structural components are usually custom-designed for the ride, and clearly need assessing individually. Mechanical components, on the other hand, can often be proprietary items, but they still need assessing, in view of the loads and number of load cycles that they often experience.

It is necessary to design for avoidance of fatigue, and not purely to rely on inspection for safety. The ride should have a reasonable amount of built-in quality, which reduces vulnerability and can reduce inspection requirements. The purpose of inspections is not primarily to discover design faults.

For clarity, the following terms are defined:

- Design life for the ride / component. This is the specified life that is required.
- Calculated fatigue life. This is the predicted time to failure, with any normal safety margins included. It is calculated at the design stage, and checked in the design review. It should normally be longer than the design life, or longer than the required replacement time.

- Inspection interval – this is the required time between inspections, to give the appropriate levels of safety.

5.2 DEFINITION OF DESIGN LIFE

A required design life should be stated in the design brief for the ride. In practice, it seems that this is not always done. A required operating life of 10years is a common default minimum in some industries.

For further operation beyond the design life, the design review should be revisited, and the Operating Instructions Inspection /Maintenance requirements generally will need to be revised. This may include the necessity of conceding the presence of a potential crack, and performing fracture mechanics based calculations.

Fatigue life is determined by the number of reversing load cycles, more than the elapsed time. A typical operating profile for design purposes needs to be specified, giving number of cycles and load magnitudes. For design purposes, intensive seasonal usage should be allowed for.

For crane design, duty factors (or equivalent) are used, to give loading spectra which depend on the type of usage. A similar type of concept could be developed for fairground rides, to capture different modes of operation.

The minimum life should apply to all components and parts, except for those that can easily be replaced – in which case the Maintenance Instructions should clearly state the time to replacement, and any other requirements.

5.3 PERFORMING A FATIGUE ANALYSIS

There are a number of codes that can be chosen to perform a fatigue assessment, including BS7608, Eurocode 3, etc. These offer acceptable alternatives, and advice is given in the NAFLIC guidance document (Ref. 7).

These codes all specify fatigue curves which include safety margins to cover the normal variability between nominally identical welds which meet code requirements. Typically the curves correspond to two standard deviations below the mean, which is approximately a 2.5% chance of failure. It should be remembered that sub-standard welds would have a poorer fatigue performance than this.

Prediction of the accelerations and loads experienced by the ride is an important area. It has been noted (Ref. 6) that this is a frequent failing of design calculations, and some practitioners have observed that fatigue life calculations do not always agree with actual service experience. Therefore, it is important to emphasise that calculations must be appropriate for the complexity of the ride motions. Safety factors should be used to cover uncertainties and variabilities, to err on the cautious side. The calculated accelerations and stresses can also be confirmed by measurements on existing rides, and this may allow some of the conservatisms to be relaxed.

Required safety factors on calculated fatigue life should be chosen. The choice on margins also depends on the uncertainty / variability in the ride, and on whether the calculations have been done using best-estimate or worst bound inputs. As a baseline, factors of at least 2 on life are normally required for components with any degree of criticality, and larger margins up to 5 for more critical elements.

We would recommend caution before using a horizontal endurance limit on a fatigue curve. Whilst it is sometimes mentioned in documents describing fatigue assessment methods for fairgrounds, it is not applicable to many situations. For welded connections, or areas which can experience corrosion (even locally, such as at crevices or contact regions), it should not be used.

It is strongly recommended that the reviewer visits the ride, to verify that the fabrication quality, condition, and operation supports the design assumptions and calculated design life. These all have a strong influence on the fatigue performance of the ride.

5.4 PRACTICE IN OTHER INDUSTRIES

Key points from the Practice in other industries are summarised as follows:

- Other industries with safety critical plant have clear requirements to state a required design life. After the design life has passed it is still possible to continue operation, but a review is required, and an increased level of fitness-for-service checks and other inspections is normally required. Setting a minimum fatigue life at least ensures a minimum baseline level of fatigue resistance.

- The power, process and offshore industries tend to perform thorough fatigue assessments, due to the high asset value and the catastrophic consequences of failure. These industries typically require a minimum safety factor of 2 on fatigue life, and often more for critical items, such as a factor of 3-5.

- In some industries, for example for wind turbines, the fatigue requirements are slightly less stringent, because there is less opportunity for harm or loss of life. No additional safety margin on fatigue life is required.

- The bridge industry does not generally require additional safety factors for fatigue, because the vehicle loading predictions are generally conservative.

- Cranes have some similarities to fairground rides in that the operation of the crane/ride will not be known precisely at the design or even review stage. The fatigue assessment (and strength assessment) of cranes defines standard loading spectra, in terms of parameters such as 'duty factor', etc. The parameters, or duty factors, include total use (no of cycles), average distance of movement, frequency of loads (load spectra for variation) and average number of accelerations per movement. These are given in BS EN 13001-1:2004 (Ref. 9).

- The LOLER regulations for lifting equipment (LOLER) are based on the Health and Safety at Work act.

  LOLER uses risk assessment principles to identify the levels of protection and control required [para 12 – 17].

  Regulation 4 covers strength and stability. Within this regulation “adequate strength” is referred to, and also that “the lifting equipment selected ***should not be unduly susceptible to any of the foreseeable failure modes likely to arise in service, for example fracture, wear and fatigue***” [para 99]. Also, “the lifting equipment used should provide an appropriate factor of safety against failure under foreseeable failure modes” [para 100]

Regulation 5 covers the special case of lifting equipment used for lifting persons; states that the "…safety coefficient relating to its strength of at least twice that required for general lifting operations…" [para 159].

Regulation 9 covers thorough examination and inspection; "the risks which could arise from the failure of the lifting equipment will determine how thorough the examination needs to be" [para 296].

5.5 STRUCTURAL FATIGUE – KEY POINTS

Key points on Structural Fatigue are summarised as follows:

- Operating experience has shown that structural fatigue is the largest single contributor to serious fairground incidents, causing a third of them. The damage can be hard to see, and generally requires specialist Non Destructive Testing to identify it.

- Rides should be designed to avoid fatigue, as a basic design approach. This avoids undue susceptibility to fatigue, and reduces the likelihood of onerous inspection regimes. The purpose of inspections is not primarily to discover design faults.

- A required design life should be stated in the design specification for a fairground ride.

- Safety factors should be applied on calculated fatigue life. These will often be a factor of at least 2 on life for components with any degree of criticality, and 3-5 for more critical components, though this depends on the variability of the loading, and whether best estimates or worst bounds have been taken.

- Evaluation of accelerations and loads is an area of uncertainty. It is necessary to have enough level of detail in the dynamic calculations, and if possible to measure existing rides to confirm the levels predicted.

- For welded connections, or areas which can experience corrosion (even locally, such as at crevices or contact regions), a fatigue endurance limit is not applicable.

6 INSPECTION FOR FATIGUE DAMAGE

This section deals with the setting of the Inspection Requirements for fatigue. This should be done by the designer or design reviewer responsible for the structural and mechanical aspects of the ride, in collaboration with a qualified inspector. The points raised here cover both the Inspection and Maintenance Requirements.

The implementation of these requirements by the inspection body / inspector is not discussed here, since it is handled by the ADIPS scheme and various other requirements.

6.1 THE INSPECTION REQUIREMENTS DOCUMENT

The importance of the Inspection Requirements document is emphasised. It is one of the most important statements from the designer. It is a mandatory requirement, not merely an aim which can optionally be achieved.

As part of the design review process, the original Inspection Requirements document will be independently reviewed. This is a highly important part of the design review. There is little code guidance given on the decision process involved here, so it is recommended that care be taken to ensure that sound and impartial engineering judgement is used here.

A clear concise statement of the Inspection Requirements is essential, such that the controller and inspector can easily comprehend and implement it. It needs to state the inspection intervals for each location, the techniques to be used, and the level of disassembly required.

The Inspection Requirements document should be seen as a 'live' document, since it needs to take account of all the known information about the ride. For example, service experience may influence future inspection requirements.

Since the Inspection Requirements document is likely to adapt with time, it is essential to have a good change control process. This needs to include independent review of any changes to the inspections of safety critical parts. It has been observed in some instances that this can be a weak point in the current industry practice.

If any aspects of the Inspection Requirements cannot be achieved, this needs to be classified as a departure. This needs to be formally assessed (it is included under the list of changes for which a design review is required), and recorded. The response is either to catch up with the inspection, agree an individual deferral, or change the inspection requirements (which would require an independent review).

It is suggested that limits for deferral on a single inspection be given. Following deferral, the subsequent inspection would need to be brought back on the original schedule.

6.2 SETTING OF INSPECTION INTERVALS

From NAFLIC Bulletins it is apparent that a significant number of cracking incidents occur due to inadequate inspection intervals. This highlights the importance of decisions on inspections.

Setting inspection intervals depends on a number of factors, including:

- Calculated fatigue life

APPENDIX A – CRITICALITY LEVELS

This Appendix discusses various points relating to the use of criticality levels. These would need to be worked up in detail for widespread use.

A.1 Setting criticality level

The following factors could be considered in setting a level of detail for the safety management of the ride:

a) A risk assessment or hazard identification,

b) experience,

c) precedent,

d) possibly a simple measure, e.g. kinetic and potential energy levels. Further work is recommended to identify and specify these ‘rules of thumb’.

The hazard level, redundancy level, ease inspection, forewarning of failure, would need to be included. In practice, risk / hazop / hazid assessment does often do not look in detail at structural aspects. This would need to be addressed.

Experience has shown that European practice sometimes has a different understanding of what elements should be included in a risk assessment, on the role that risk assessment has in the design, and on how important it can be. This may require some development of understanding between supplier and ride controller.

The use of experience and precedent is helpful, but it can lead to a gradual drift in safety standards. This was identified as one of the causes in the Piper Alpha disaster, for example. The solution was to emphasise safety as a priority, and provide written guidance and training.

A.2 Application of criticality level in practice

The aim in setting a level of criticality for the ride is to help to define what level of detail is required for the design, design review, and safety management. The aim is to try and ensure that the complex high risk rides have a thorough review whilst allowing a more pragmatic approach for the simpler low risk rides.

A current best practice design review will already have assessed a ride to an appropriate level of detail. Some preliminary suggestions are made below; further work is recommended to specify the assessment detail for different criticality levels.

- Some codes, notably prEN 13814, give some specific guidance for certain rides. For example, in Annex B. Examples of this fairly prescriptive approach have not been found in other relevant current codes. The examples in Annex B appear to cover basic rides which are not driven by motor power. If there are further examples of specific guidance in codes, then these could help to set a baseline level.

- Broadly, high criticality level rides would require a full independent analysis using different software for the structural calculations. The inspection intervals specified would need to be justified by calculations.

- Medium criticality level rides would require some intermediate level of review. Note HSG 175 and other codes recommend that whenever computer software is used in calculation, different software should be used for the review.

- Low criticality rides could have a more pragmatic approach.

APPENDIX B - INFORMATION REQUIRED FOR A DESIGN REVIEW

This Appendix discusses some of the information required for the design review.

B.1 Required documents

It is important for purchasers of foreign rides to require that all information be provided so that a full design review can be performed, including structural analysis, calculations as well as risk assessments.

Some reviewers have a standard checklist for required documents and information. The industry may wish to develop this for wider use.

Required documents include:

1. Design calculations for all aspects of the ride. Full and comprehensive calculations required, including risk assessment

2. Existing full design review if available

3. Technical drawings

4. Operations Manual – with all the relevant parts as specified in HSG 175 (Operating Instructions, Inspection Requirements, Maintenance Requirements, etc).

5. Assessment of conformity to design (if available)

6. Initial test results (if available)

If there are documents missing then they must be requested. A design review is a check, and the reviewer would needs to halt the review if appropriate documentation is not forthcoming.

Note that this report is essentially dealing with new fixed rides. If the ride were travelling, second hand, an old design, or a modification of an existing design then additional documents would be required, to provide some history of operating experience.

Other information required would include:

1. Whether the ride is a new design, or a modification, or a new manufacture of an old design?

2. Where is the ride from? e.g., UK, Germany, China, Italy, etc

3. Is there any operating history etc available, for this actual ride or for this type of ride?

4. Is the log book up-to-date with any inspections/maintenance/modifications?

APPENDIX C – RECORDING OF INFORMATION

This Appendix discusses various points on the communication of information between the various parties involved.

C.1 Contents of a design review report

Best practice design reviews have a summary sheet at the front of the review, stating what the review is for, the scope etc. and a clear section for actions required.

It is recommended that this be encouraged across the industry. Design review reports can be large documents, and it is beneficial that the main points from the review be summarised and communicated.

It is suggested that the following aspects are important to communicate.

- A declaration, such as in HSG 175, that the device is safe for continued / temporary use, with any reservations, actions required, and the expiry date.
- A statement of the reviewer's competence against each of the aspects reviewed.
- A clear and comprehensive set of Inspection Requirements. This should also highlight any areas which require particular attention. It should be sufficient for the inspector to take and use directly.
- List of codes and standards used, and main assumptions made. The fabrication quality should be included.
- Details of documents reviewed.
- Reference to the previous design review document (if it is a change).

C.2 Template summary sheet for design review

It would be useful for the industry to develop a template for the design review, to give some broad consistency. An example template for the design review is offered below, to illustrate what is being suggested, and for discussion purposes. It would need to be worked up into a useable format for all concerned.

Summary Sheet for Design Review	Delete as appropriate: ~~Interim~~ / Partial / ~~Full~~ Review		
Reference & date for this sheet	SuperX-Ride1, Review3, 19-May-02 - Summary		
Ride identity	Complete in full		
Name of device	Xxxx Xxxx	Generic type of device	Xxxxxxxxxxx xxxx
Unique device marque, serial number or identification number,	Xxxxx-xxx	Trade association number for the device (if known)	xx-xx-xx
Name and address of designer	X Xxxx Ltd, Xxxxxx, Xxxxxxx, Germany	Name and address of manufacturer	X Ltd, Xxxxxx, Xxxxx, Germany
Date of manufacture	September 2001	Name and address of previous owner	Xxx Xxxxx, Xxxxx, UK
Name and address of current owner	Xxx Xxxxx, Xxxxx, UK	Name and address of controller	X X Xxxxx, Xxxxx, UK
Criticality of ride	~~Low / Medium~~ / High	Date and place of review	12-Apr-02, Xxxx, UK
Current version of Operations Manual	Reference number, Issue number and date Xxxxx-xx Version 12 , 10-Apr-02		
Reason for review	Modification to Inspection Requirements		

Scope of review		Name, qualification, company and position of reviewer with relevant report no. and section,
	Scope of review required (controller to fill in)	Completed (reviewer to fill in and sign)
Structural	Yes	J Bloggs, MIMechE, Xxxx Ltd, Chief Engineer
Mechanical	Yes	T Smith, MIMechE, Xxxx Ltd, Design Engineer
Civil (Foundations)	Not required	-
Control systems and instrumentation	Not required	-
Electrical systems	Not required	-
Ergonomics – passenger interactions and restraints	Not required	-
Other Please specify:	Not required	-
Design Review report /s	Unique report number, Issue number and date, pages included X1234-321, Issue 1, 3-May-02 A9876-987, Issue 1, 15-May-02	
Confirmation that Testing, Inspection and Maintenance requirements have been reviewed and actions are stated in the Design Review report (relevant signatures)	J Bloggs T Smith	

<table>
<tr><td>Actions required</td><td>Action (reviewer to fill in)</td><td>Required completion date (reviewer to fill in)</td><td colspan="2">Completed (controller to fill in name and date)</td></tr>
<tr><td>Actions from Design Review report</td><td>1. Modify Operations Manual to include changes to Inspection Requirements
2. Implement modified inspection requirements
3. Brief ride operatives on loading of ride and speed control</td><td>31-Jun-02
31-Jul-02
25-May-02</td><td colspan="2"></td></tr>
<tr><td><u>Integration of current review</u></td><td colspan="4">This part enables a partial review to be used against the baseline of a previous</td></tr>
<tr><td>Previous statement of adequacy of ride</td><td colspan="4">SuperX-Ride1, Review3, 19-May-02 - Summary</td></tr>
<tr><td>Confirmation that the required scope of current review covers all changes</td><td colspan="2">Confirmed. D Brown, MIMechE, Xxxx Ltd, Chief Engineer
(ride controller)</td><td colspan="2">Confirmed. K Smith, MIMechE, Xxxx Ltd, Chief Engineer
(independent person)</td></tr>
<tr><td>Confirmation that the Operations Manual includes all relevant current information</td><td colspan="2">Confirmed. D Brown , " "
(ride controller)</td><td colspan="2">Confirmed. K Smith, MIMechE, Xxxx Ltd, Chief Engineer
(independent person)</td></tr>
<tr><td>Confirmation that no further review is required</td><td colspan="2">Confirmed. D Brown , " "
(ride controller)</td><td colspan="2">Confirmed. K Smith, MIMechE, Xxxx Ltd, Chief Engineer
(independent person)</td></tr>
<tr><td><u>Declaration:</u></td><td colspan="4">On the……………………………………………….. …………………………... ……………..……………..
I/we have reviewed this amusement device and confirm that the device is safe for continued operation provided that :
- it be operated according the the above-referenced Operations Manual
- the above-stated Actions be carried out by the required dates
- No signification modifications have occurred since date of review</td></tr>
<tr><td>Expiry date for Declaration, and reason for expiry</td><td colspan="4">31-Apr-04. Inspection requirements need to be reviewed after standard minimum operational time of 2 years.</td></tr>
<tr><td>Signature</td><td colspan="4">PSmith P Smith, MIMechE, Senior Engineer</td></tr>
<tr><td>Representing company</td><td colspan="4"></td></tr>
<tr><td>Membership number of industry registration scheme</td><td colspan="4"></td></tr>
</table>

A supporting template is also provided to give some additional detail about the scope of the review, and other points of observation or concern that need to be raised. This is given as follows, again for illustration and discussion purposes.

Supporting Sheet for Design Review	Delete as appropriate: ~~Interim~~ / Partial / ~~Full~~ Review
Reference & date for this sheet	SuperX-Ride1, Review3, 19-May-02 – Supporting
Documentation	Give document title, number, date and issue as well as any comments
Owner instructions / responsibilities and quality of	Xxxx, Date Sept 2001, Issue 3 – Adequate for structural aspec
Ride operator instructions and quality of	Xxxx, Date Sept 2001, Issue 3 – Adequate for structural aspec
Maintenance instructions and quality of	Xxxx, Date Sept 2001, Issue 3 – Adequate for structural aspec
Inspection instructions and quality of	Xxxx, Date Sept 2001, Issue 3 – Clear, supplemented by this review
NDT (structural) – clarity and quality, any further requirements?	Xxxx, Date Sept 2001, Issue 3 – Adequate for structural aspec
Compiled operations manual and other constituent parts and quality of	Xxxx, Date Sept 2001, Issue 3 – Adequate for structural aspec
Pre-commissioning testing and inspection information supplied and quality of	None
Date and extent of any previous design review and quality of	N/a
List of design documentation supplied (calculations and drawings) and their quality	List and reference documentation or give report section reference with full list Calculations xxxxxx parts 1 – 25, dated June 2001 Drg numbers xxxxxx-1 – 10 and 15-25, Rev A, dated June/July 2001 Supplementary correspondence with manufacturer, Ref. Document Transfer Sheet DT-X2341-D1, 5-Jan-02
General history and condition	Complete in full
Criticality of ride (L/M/H)	Medium
Size, speed, type of operation	Xxxx xxxx xxxx
New / modified	New
History of ownership / usage to date	N/a
Condition from site visit and close visual inspection	N/a
Quality of fabrication	Propietary components sound, electrical installation sound, structural welded details ragged in places
Codes and standards used	List and reference documentation or give report section reference with full list EN xxxxx HSG 175 Xxxxx
Main assumptions	Complete in full, or give report section reference with full list Assumed that fabrication as indicated in design drawings, not modified.. Ride loading and turnround time assumed. Assume that initial test discovers no unforeseen issues. See review report Section xx for further detail.

Precedent / other similar rides		Complete in full, or give report section reference with full list	
Precedent - how many other such rides existing?		5 similar rides operating around France and Germany	
Any problems with existing similar rides?		Xxxxx	
Interaction		Complete in full	
Has this summary been discussed with the owner and ride operator? Have they given their understanding of the key issues?		Yes Yes	
Outcome		Complete in full, or give report section reference with full list	
Main Risk areas & mitigations	Major consequence	Base of main boom, all weld locations Swinging arm attachments to support spindle Support pins and spindles of compartments	MPI and UT inspection, da visual as backup check. Prohibit reversing operatio
	Frequent occurrence	Passenger restraint not locked Trip on exit from compartment	Operative to check passengers. Clear signs an handrail.
Actions required		See associated Summary sheet	
Concerns / reservations encountered during review (comments which do not mandate specific action for sign-off)		Current version of design drawings not always clear – would benefit from a definitive drawing of the critical components (boom, swinging arm, compartment supports) Little information on actual ride cycle – would benefit from more detail on current operation Cycle counters would enable the inspections to be targeted more definitely more Speed limiters	
Overall Conclusion of Design Review (include statement of extent)		This Review has covered the following scope : - Structural parts of the ride. It has included consideration of : - Design - Operating Instructions - Testing, Inspection, and Maintenance requirements From this review, it has been found that the ride is fit for purpose, provided that - The ride be operated according to the Operations Manual - the above-stated Actions be carried out by the required dates - No signification modifications have occurred since date of review	
Expiry Date, and reason		Expires 31-Apr-04, due to requirement for 2 year review of the ride and its operations.	

APPENDIX D – RISK ASSESSMENT

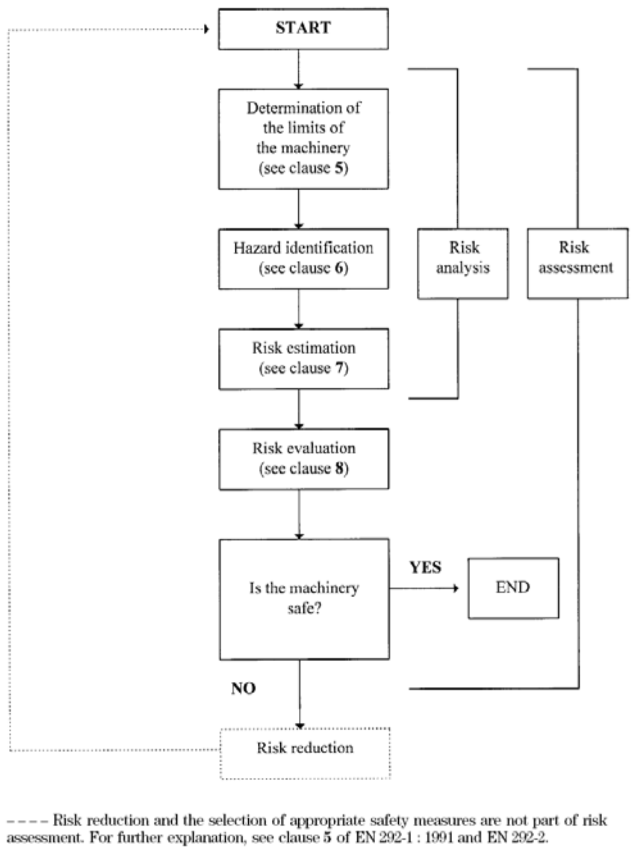
D.1 Principles of Risk Assessment (ISO 14121 previously EN 1050:1997)

Risk assessment is a series of logical steps to enable, in a systematic way, the examination of the hazards associated with machinery. Risk assessment is followed, whenever necessary, by risk reduction as described in clause 5 of EN 12100-1:2003 (previously EN 292-1:1991). When this process is repeated it gives the iterative process for eliminating hazards as far as possible and for implementing safety measures. Risk assessment includes (see figure) :

- risk analysis;
    - a) determination of the limits of the machinery (see clause 5);
    - b) hazard identification (see clause 6);
    - c) risk estimation (see clause 7);
- risk evaluation (see clause 8).

Risk assessment relies on decisions made using the judgement of the risk assessors. These decisions shall be supported by qualitative methods complemented, as far as possible, by quantitative methods. Quantitative methods are particularly appropriate when the foreseeable severity and extent of harm are high. Quantitative methods are useful to assess alternative safety measures and to determine which gives better protection.

The decision making process should question whether the structural components, mechanical, electrical or control and instrumentation elements within the design are 'Safe enough' and if the risk has been adequately reduced. This requires a direct relationship between the structural design and the risk assessment to enable the questions to be answered. Risk Assessment then forms an input into the design process when considering the function of the component on the structure, any hazards that may arise, the severity and frequency of



– – – – Risk reduction and the selection of appropriate safety measures are not part of risk assessment. For further explanation, see clause 5 of EN 292-1 : 1991 and EN 292-2.

Figure 1. The iterative process to achieve safety

EN 1050:1997 Figure 1 - Copyright BSI © 1997

the hazards and whether additional measures may be required to ensure that the risk has been adequately reduced.

EN 1050 provides a simple mathematical formula for evaluating hazards and determining the level of risk. The formula is:

LO X FE X DPH X NP = Risk level

Where:

LO = Likelihood of occurrence, ranging from 1 (almost impossible) to 15 (certain)

FE = Frequency of exposure, ranging from 0.5 (annually) to 5 (constant)

DPH = Degree of possible harm, ranging from 0.1 (scratch to 15 (fatality)

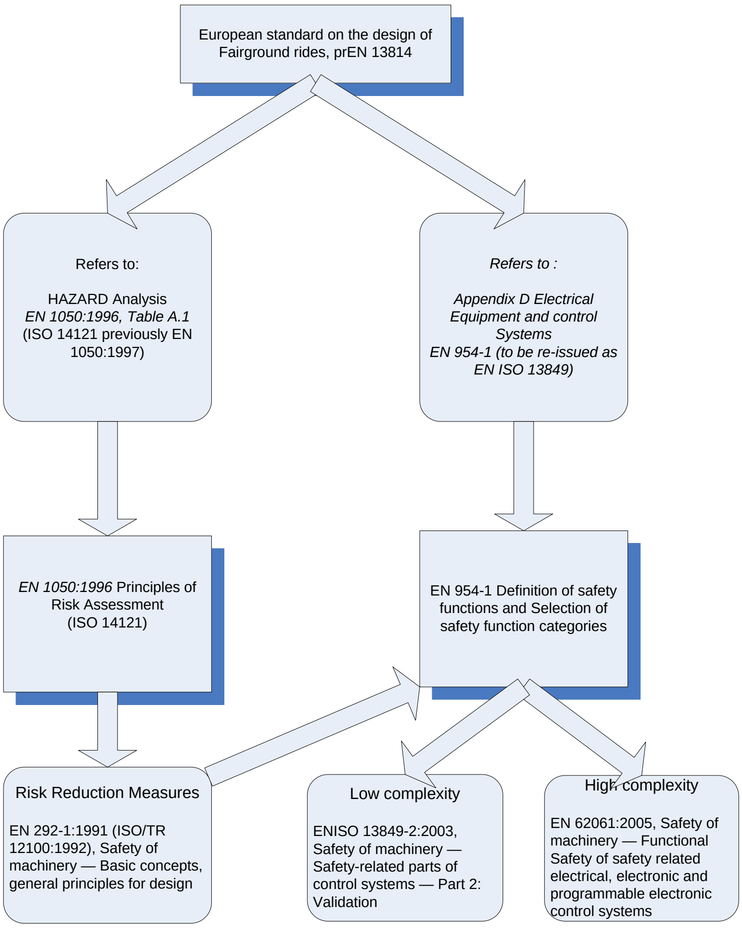
NP= Number of persons exposed, ranging from 1 (1 or 2 people) to 12 (50 or more people)

The level of risk posed by the failure of control systems has led to specific requirements to be set for control systems based on the complexity and level of risk. EN-954-1 provides a qualitative form of risk assessment (for non-complex and non-programmable control systems) and, more important, describes five levels of control circuit performance in the event of a component failure. These levels are identified as categories B and 1 through 4. For more complex rides, including those with any programmable control systems, the designer is guided to use the EN62061 standard. This aspect is considered further in the section on Safety Integrity of Control Systems for Fairground Rides.

D.2 Overview of the Risk Assessment Process in the Safety of Machinery Standards

In order to demonstrate that all risks have been identified and that sufficient measures are in place to ensure risks are ALARP and that risk assessment underwrites the design, it is recommended to apply a comprehensive approach to risk Assessment. This process is already well developed in the Safety of Machinery Standards.

It is evident from the list of hazards listed in the previous section, and the references in prEN 13814:2004 that the application of risk assessment is based heavily on the process as described in the safety of machinery standards. An overview of the references to the safety of machinery standards with respect to risk assessment is presented in the following flowchart.



Arguably a risk assessment of the whole amusement devices can be considered to be an integral part of the design process and by extension as part of the design review process. A design review performed without due consideration of the risk assessment (or development of a risk assessment if the designer has not provided a risk assessment) should be a key element in the design review.

However due to the various changes in the safety of Machinery standards and a move from EN standards to ISO Standards, the status of standards (EN, ISO and IEC) is not clearly defined. An overview of the main standards for risk assessment are presented in the table below.

EN Standard	ISO Standard
EN292:1991 *(Withdrawn)* Safety of machinery – Basic concepts, general principles for design.	ISO12100-1:2003 Safety of machinery – Basic concepts, general principles for design – Part 1, basic terminology, methodology
EN1050:1997 Safety of machinery – Principles of Risk Assessment	ISO14121:1999 Safety of machinery – Principles for Risk Assessment
EN 954-1:1997 Safety of machinery – safety related parts of control systems – Part 1 General principles for design	Draft ISO13849-1 * Safety of machinery – safety related parts of control systems – Part 1 General principles for design
EN 954-2:1991*(Withdrawn)* Safety of machinery – Safety related parts of control systems – Part 2 Technical Principles	ISO13849-2 Safety of machinery – Safety related parts of control systems – Part 2 Technical Principles
EN 62061:2005 (IEC 62061) Safety of Machinery – Functional safety of safety related electrical, electronic and programmable electronic control systems	

* Note position statement from the HSE on the draft ISO13849-1 standard: The development process for the revision of ISO 13849-1 will continue for at least a number of months. Until the revision is ratified, designers can continue to use the current version of ISO 13849-1 (BS EN 954-1: 1997). HSE policy is that ISO 13849-1 [BS EN 954-1: 1997] is suitable for low complexity electrical/electronic systems and systems employing non-electrical technologies. For high complexity electrical/electronic systems, including those employing programmable electronic technologies, the use of IEC 62061 is considered best practice.

** The broad scope of BS EN ISO 13849-2 encompasses the validation of safety related parts of control systems that use mechanical, pneumatic, hydraulic and electrical (and electronic) technologies, but machine builders working with programmable electronic systems are directed towards EN 62061:1995.

D.3 European Standard on the Design of Fairground Rides and Risk Assessment

The European standard on the design of Fairground rides, prEN 13814, attempts to specify the minimum requirements necessary to ensure the safe design, calculation, manufacture, installation, maintenance, operation, examination and testing of the following: mobile, temporary or permanently installed machinery and structures e. g. roundabouts, swings, boats, ferris wheels, roller coasters, chutes, grandstands, membrane or textile structures, booths, stages, side shows, and structures for artistic aerial displays.

A comprehensive set of standards has been developed for the safety of machinery. It is important, however, to realise that "equipment for use in fairgrounds and/or amusement parks" is specifically excluded from the Machinery Directive. All standards, including BS EN 954, under this Directive therefore have no legal standing as far as fairground rides are concerned.

The approach to risk assessment in prEN 13814 is disconcertingly unclear. No direct reference to risk assessment, risk reduction as a general design principle for all elements of the design is stated. Although the standards on safety of machinery are not applied to amusement devices, the prEN13814 standard refers to the safety of machinery standards in several places. Reference is made to a Hazard analysis, however without stating the purpose of the Hazards analysis, requirements for, the role the hazard analysis is to perform, or the process it is applied to (see extract below). Where reference to risk assessment or risk reduction is made it is specifically applied to, risk reduction measures on passenger access and movement in or around the ride or specific aspects concerning the passenger units, criteria with respect to passenger characteristics, wind measuring devices. Specific references to the safety of machinery standards listed are discussed below:

1. Hazard Analysis
2. Risk reduction
3. Guards on machinery
4. Control Systems

The contents listing for clause 6.1 on risk reduction contains the following sub-sections listed below, one of which refers to hazard analysis:

6.1 Risk reduction by prevailing design and safety measures.

6.1.1 General

6.1.2 Hazard analysis

6.1.3 Risk reduction for platforms, ramps, floors, stairs and walkways

6.1.4 Risk reduction by the use of railings, fencing and guarding

6.1.5 Risk reduction in the case of access and egress

6.1.6 Risk reduction for passenger units.

6.1.7 Risk reduction by special provisions

No discussion of the process and no reference to an overall framework for risk assessment or risk reduction process within the context of prEN 13814 is given. In fact the standard claims to have unified the design approval, examination and safety precautions for a majority of rides in the chapter. The section on hazard analysis does refer to the EN1050 standard "Principles of risk assessment", however the chapter is labelled as hazard analysis, and seems to focus on the hazard analysis part of a risk assessment (see extract below). A table providing additional hazards specific to passengers / spectators has been provided.

6.1 Risk reduction by prevailing design and safety measures

6.1.2 Hazard analysis

For guidance on general principles of Hazard Analysis see EN 1050:1996, Table A.1 with the exclusion of items 8.6 and 37 and when considering passengers also item 8.5, and compare the applicable main hazards for amusement devices listed in annex I.

Annex I (informative) List of hazards

The main hazards, hazardous situations and events for spectators and passengers during the operation and use of amusement rides is defined in this Annex to the prEN 13814:2004 standard.

It would be difficult to infer from this reference that the risk assessment process as put forward in the safety of machinery standards (EN1050) is to be applied in its entirety. EN 1050 can be considered to be the starting point to the use of risk assessment in the safety of machinery codes. A complete list of hazards from both prEN 13814:2004, *Annex I*, and EN 1050:1996 , *Table A.1,* is presented in Appendix E. The following chapters in prEN 13814 focus on general risk reduction measures to passenger movements and passenger containment. No discussion on other potential risk reduction measures that could be considered is mentioned. The one specific reference to risk assessment is in the chapter risk reduction for passenger units on criteria for passenger restrain devices.

Chapter 6.1.6 Risk reduction for passenger units,

Section 6.1.6.2.4 Application criteria from passenger restraint devices resulting from risk assessment

An additional reference to the Safety of Machinery standards on the use of guards is also mentioned.

6.1.4.6 Guarding of dangerous parts of machinery

Any hazardous machinery part built into amusement devices which passengers shall be secured with guards in accordance with EN 292-1 and EN 292-2.

A standalone part of the standard is Annex D, which relates to the electrical and control systems, and is referenced in a few specific cases in the main text of the standard (specifically when block zone control systems are mentioned). In the introduction Annex D is considered to be normative. In this case the Safety of Machinery standards for Risk Assessment are applied however with the main focus on the control systems, the forces that passengers may be subject to on the rides and passenger containment. A section has been dedicated on determining safety related parameters, where the effect of ride operational characteristics (speed) on the structures and passengers should be considered.

Annex D Electrical Equipment and control Systems (normative)

- *Control systems incorporating pneumatic, hydraulic and mechanical elements shall be in accordance with EN 954-1 (now issued as EN ISO 12100) and with the risk assessment conducted in accordance with EN 1050:1996, Table A.1.*

- *D.2.5 Safety related parameters*

  Means shall be provided to ensure that the values of the safety related parameters stay within predetermined levels defined by the risk assessment.

  Speed is an important safety critical parameter for amusement devices where accelerations, and consequently forces are dependent on the speed of amusement ride elements. Therefore, speed control can prevent hazardous effects on structures and passengers.

  The risk assessment shall evaluate the effects on the amusement device and passengers due to any achievable speeds. In general, if the maximum achievable speed is lower *than or equal to the maximum operational speed, the control system does not require additional speed control circuits, but if the maximum achievable speed is greater than the maximum operational speed, additional means may be necessary to ensure that the maximum operational speed is not exceeded. Also if the machine does not reach, or falls below, the minimum operational speed, additional means may be needed to ensure that the minimum operational speed is achieved or a safety stop is performed. The need for, and the integrity, of these means shall be determined by risk assessment.*

D.2.6 Passenger restraint status

Where a control system is involved in the operating, interlocking or monitoring of passenger restraints, its function and integrity shall be determined in a risk assessment. In addition to the requirements of 6.1.6.2.4 the following prEN 13814:2004 (E) 157 guidelines should be taken into account. Any departures from these guidelines shall be detailed and justified in the risk assessment.

It is possible from the way the guidance has been set out that designers may limit any risk assessment to a general review of the Hazards in EN1050 (supplemented by prEN 13814) and to support the design of the control system. For the structural and mechanical components of the ride and potential impact of failed items with spectators and or ride participants almost complete reliance is placed on the deterministic criteria and limits within the standard. This is in contrast to the Safety of Machinery standards where risk assessment underpins all aspects of the design.

D.4 ISO Technical Report, PD ISO/TR 18569:2004

The process for applying risk assessment through the design phase in the standards is described in the ISO Technical Report, PD ISO/TR 18569:2004 Safety of machinery – Guidelines for the understanding and use of safety of machinery standards. The process is presented in the three figures below:

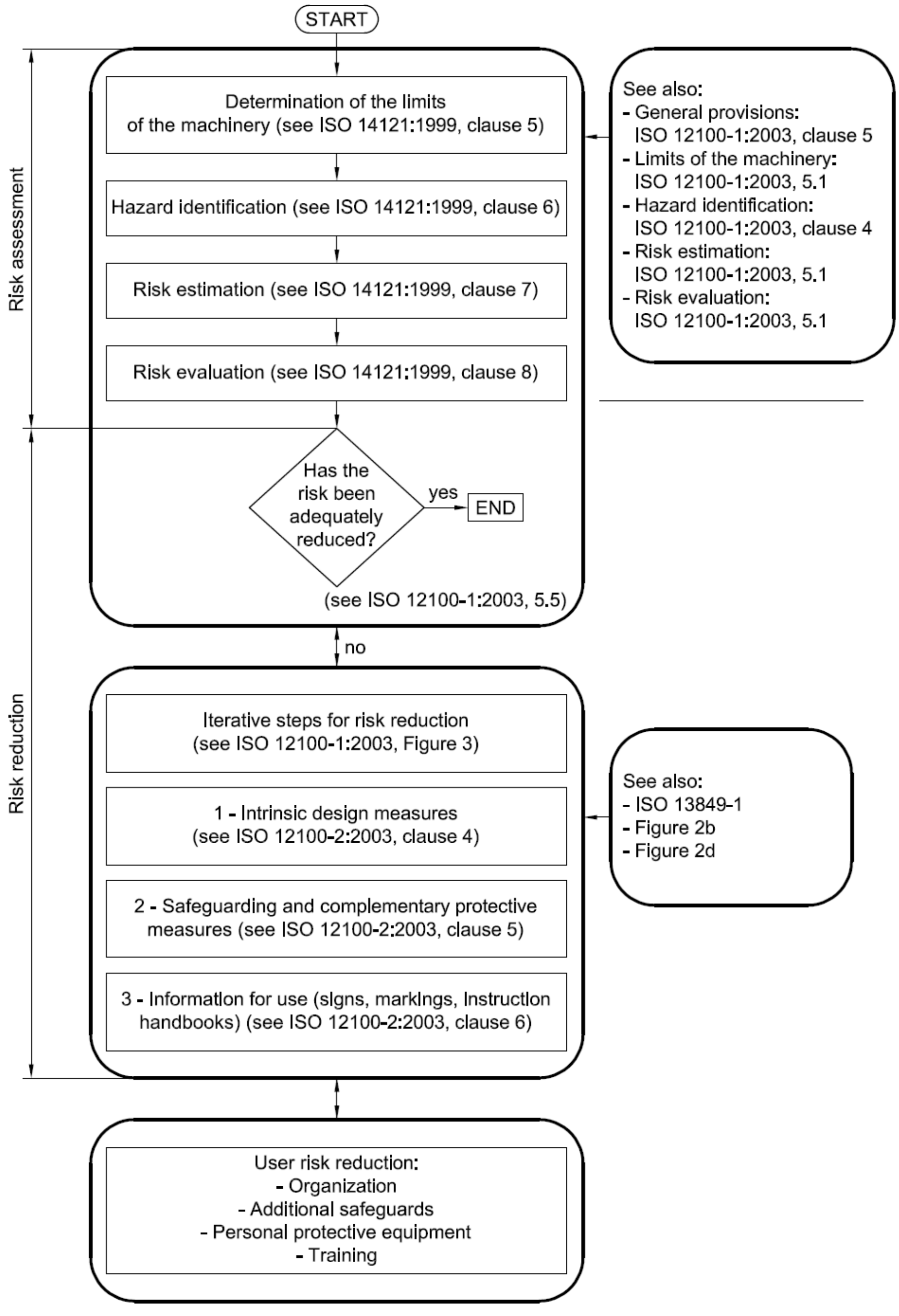
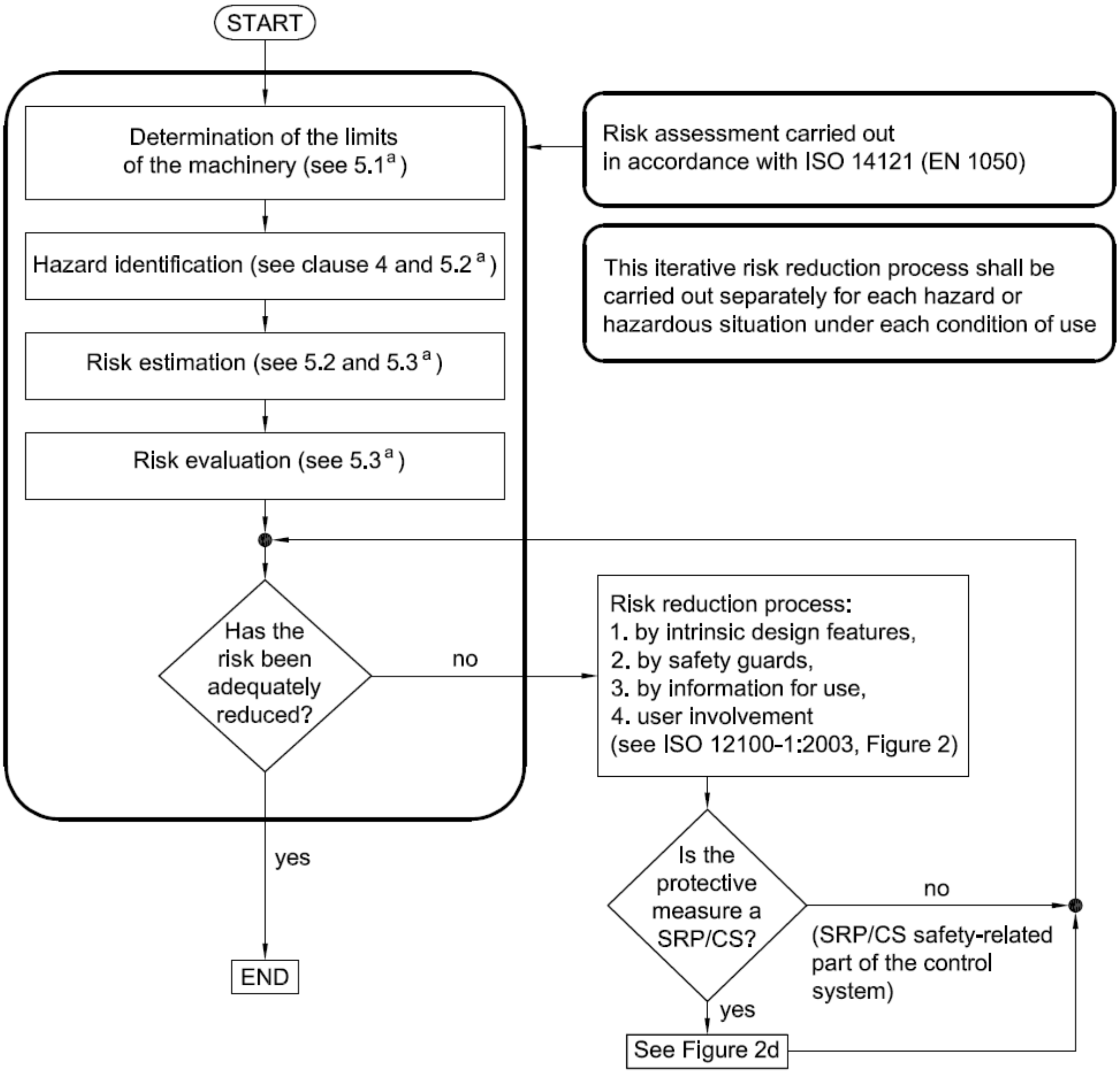


Figure 2a — Basic diagram illustrating risk assessment and risk reduction



[a] Subclause references to ISO 12100-1:2003

Figure 2c — Iterative process for the selection of protective measures

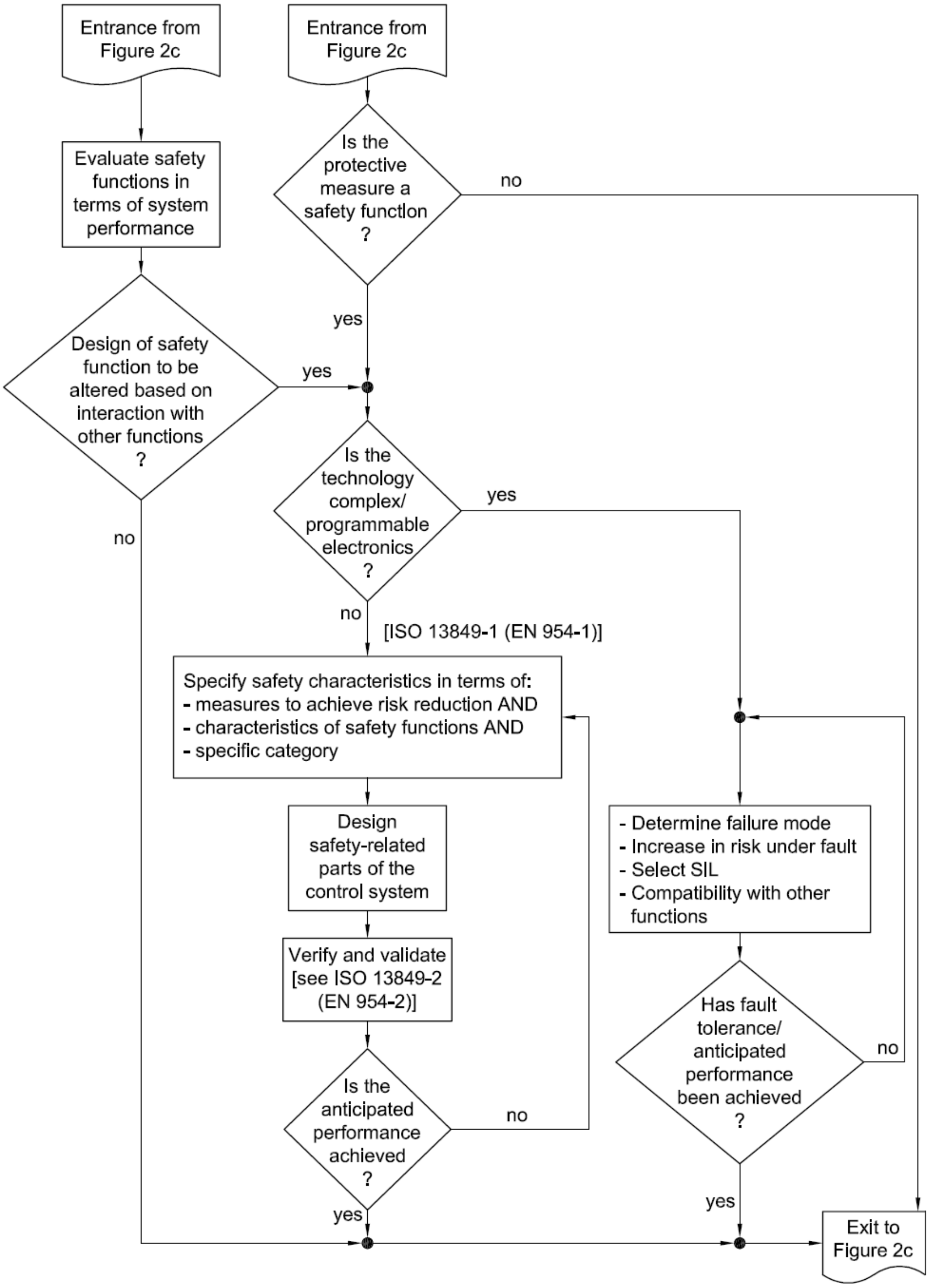


Figure 2d — Overview of the determination and validation of safety functions

APPENDIX E - HAZARDS

A complete list of hazards from both prEN 13814:2004, *Annex I* and EN 1050:1997 , *Table A.1,* (**Copyright BSI © 1997**) is presented below.

Examples of hazards, hazardous situations and hazardous events (EN 1050:1997 and prEN 13814)

EN 1050:1997, Table A.1 with Hazards deleted as described in prEN 13814 **Hazards, hazardous situations and hazardous events**	
1	**Mechanical hazards due to:** **- machine parts or workpieces, e.g.:**
1.1	Crushing hazard
1.2	Shearing hazard
1.3	Cutting or severing hazard
1.4	Entanglement hazard
1.5	Drawing-in or trapping hazard
1.6	Impact hazard
1.7	Stabbing or puncture hazard
1.8	Friction or abrasion hazard
2	**Electrical hazards due to:**
2.1	Contact of persons with live parts (direct contact)
2.2	Contact of persons with parts which have become live under faulty conditions (indirect contact)
2.3	Approach to live parts under high voltage
2.4	Electrostatic phenomena
2.5	Thermal radiation or other phenomena such as the projection of molten particles and chemical effects from short circuits, overloads, etc.
3	**Thermal hazards, resulting in:**
3.1	Burns, scalds and other injuries by a possible contact of persons with objects or materials with an extreme high or low temperature, by flames or explosions and also by the radiation of heat sources
3.2	Damage to health by hot or cold working environment
4	**Hazards generated by noise, resulting in:**
4.1	Hearing loss (deafness), other physiological disorders (e.g. loss of balance, loss of awareness)
4.2	Interference with speech communication, acoustic signals, etc.
5	**Hazards generated by vibration**
5.1	Use of hand-held machines resulting in a variety of neurological and vascular disorders

EN 1050:1997, Table A.1 with Hazards deleted as described in prEN 13814	
Hazards, hazardous situations and hazardous events	
5.2	Whole body vibration, particularly when combined with poor postures
6	**Hazards generated by radiation**
6.1	Low frequency, radio frequency radiation, microwaves
6.2	Infrared, visible and ultraviolet light
6.3	X and gamma rays
6.4	Alpha, beta rays, electron or ion beams, neutrons
6.5	Lasers
7	**Hazards generated by materials and substances (and their constituent elements) processed or used by the machinery**
7.1	Hazards from contact with or inhalation of harmful fluids, gases, mists, fumes, and dusts
7.2	Fire or explosion hazard
7.3	Biological or microbiological (viral or bacterial) hazards
8	**Hazards generated by neglecting ergonomic principles in machinery design as, e.g. hazards from:**
8.1	Unhealthy postures or excessive effort
8.2	Inadequate consideration of hand-arm or foot-leg anatomy
8.3	Neglected use of personal protection equipment
8.4	Inadequate local lighting
~~8.5~~	~~Mental overload and underload, stress~~
~~8.6~~	~~Human error, human behaviour~~
8.7	Inadequate design, location or identification of manual controls
8.8	Inadequate design or location of visual display units
9	**Combination of hazards**
10	**Unexpected start-up, unexpected over-run/over-speed (or any similar malfunction) from:**
10.1	Failure/disorder of the control system
10.2	Restoration of energy supply after an interruption
10.3	External influences on electrical equipment
10.4	Other external influences (gravity, wind, etc.)
10.5	Errors in the software
10.6	Errors made by the operator (due to mismatch of machinery with human characteristics and abilities, see 8.6)
11	**Impossibility of stopping the machine in the best possible conditions**
12	**Variations in the rotational speed of tools**
13	**Failure of the power supply**

EN 1050:1997, Table A.1 with Hazards deleted as described in prEN 13814 **Hazards, hazardous situations and hazardous events**	
14	**Failure of the control circuit**
15	**Errors of fitting**
16	**Break-up during operation**
17	**Falling or ejected objects or fluids**
18	**Loss of stability / overturning of machinery**
19	**Slip, trip and fall of persons (related to machinery)**
Additional hazards, hazardous situations and hazardous events due to mobility	
20	**Relating to the travelling function**
20.1	Movement when starting the engine
20.2	Movement without a driver at the driving position
20.3	Movement without all parts in a safe position
20.4	Excessive speed of pedestrian controlled machinery
20.5	Excessive oscillations when moving
20.6	Insufficient ability of machinery to be slowed down, stopped and immobilised
21	**Linked to the work position (including driving station) on the machine**
21.1	Fall of persons during access to (or at/from) the work position
21.2	Exhaust gases/lack of oxygen at the work position
21.3	Fire (flammability of the cab, lack of extinguishing means)
21.4	Mechanical hazards at the work position: a) contact with the wheels b) rollover c) fall of objects, penetration by objects d) break-up of parts rotating at high speed e) contact of persons with machine parts or tools (pedestrian controlled machines)
21.5	Insufficient visibility from the work positions
21.6	Inadequate lighting
21.7	Inadequate seating
21.8	Noise at the work position
21.9	Vibration at the work position
21.10	Insufficient means for evacuation/emergency exit

EN 1050:1997, Table A.1 with Hazards deleted as described in prEN 13814	
Hazards, hazardous situations and hazardous events	
22	**Due to the control system**
22.1	Inadequate location of manual controls
22.2	Inadequate design of manual controls and their mode of operation
23	**From handling the machine** (lack of stability)
24	**Due to the power source and to the transmission of power**
24.1	Hazards from the engine and the batteries
24.2	Hazards from transmission of power between machines
25	**From/to third persons**
25.1	Unauthorised start-up/use
25.2	Drift of a part away from its stopping position
25.3	Lack or inadequacy of visual or acoustic warning means
26	**Insufficient instructions for the driver/operator**
Additional hazards, hazardous situations and hazardous events due to lifting	
27	**Mechanical hazards and hazardous events**
27.1	from load falls, collisions, machine tipping caused by :
27.1.1	lack of stability
27.1.2	uncontrolled loading – overloading – overturning moments exceeded
27.1.3	uncontrolled amplitude of movements
27.1.4	unexpected/unintended movement of loads
27.1.5	inadequate holding devices/accessories
27.1.6	collision of more than one machine
27.2	from access of persons to load support
27.3	from derailment
27.4	from insufficient mechanical strength of parts
27.5	from inadequate design of pulleys, drums
27.6	from inadequate selection of chains, ropes, lifting and accessories and their inadequate integration into the machine
27.7	from lowering of the load under the control of friction break
27.8	from abnormal conditions of assembly/testing/use/maintenance
27.9	from the effect of load on persons (impact by load or counterweight)
28	**Electrical hazard**
28.1	from lightning
29	**Hazards generated by neglecting ergonomic principles**

EN 1050:1997, Table A.1 with Hazards deleted as described in prEN 13814 **Hazards, hazardous situations and hazardous events**	
29.1	insufficient visibility from the driving position
Additional hazards, hazardous situations and hazardous events due to underground work	
30	**Mechanical hazards and hazardous events due to:**
30.1	Lack of stability of powered roof supports
30.2	Failing accelerator or brake control of machinery running on rails
30.3	Failing or lack of deadman's control of machinery running on rails
31	Restricted movement of persons
32	Fire and explosion
33	Emission of dust, gases etc.
Additional hazards, hazardous situations and hazardous events due to the lifting or moving of persons	
34	**Mechanical hazards and hazardous events due to :**
34.1	Inadequate mechanical strength – inadequate working coefficients
34.2	Failing of loading control
34.3	Failing of controls in person carrier (function, priority)
34.4	Overspeed of person carrier
35	Falling of person from person carrier
36	Falling or overturning of person carrier
~~37~~	~~Human error, human behaviour~~

PrEN 13814 Table I1 **Hazards, hazardous situations and hazardous events to be considered in addition to *EN 1050:1997, Table A.1***	
Supplementary hazards due to motion of passengers on rides	
38	Hazards arising from the intensity and duration of accelerations and jerks
39	Hazards arising from the intensity and duration of forces exerted by elements of the passenger containment
40	Ejection of passengers
41	Hazards from reasonable foreseeable behaviour of passengers
42	Hazards from reasonable foreseeable operator error
Additional hazards associated with environmental conditions (particularly resulting from outdoor use of amusement devices)	
43	Hazards associated with high winds
44	Hazards associated with snow
45	Lightning strike
Additional hazards associated with emergency procedures	
46	Hazards associated with the need to evacuate passengers from remote locations (e.g. following ride breakdown)
Additional hazards associated with water (ponds, pools, log flumes, water parks, rapid rides)	
47	Drowning
48	Hazards associated with underwater maintenance and inspection
Additional amusement device hazards	
49	Injury by projectiles
Additional hazards associated with crowds	
50	Crushing due to crowd pressure
51	Problems of emergency egress as a result of pinch points etc.

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Health and Safety Executive

A review of the design review process for fairground rides

This report reviews the current usage of the 'design review' process in the UK fairground industry. Its influence in assuring the safety of rides has been evaluated, considering background perspectives from normal practice in other industries.

The UK framework and practice for fairground safety has been developed over a number of decades, which includes the involvement of a number of regulatory bodies and other organisations. Various guidance documents and publications are available, and these have been used as the baseline measure of current practice. Liaison has been established with a number of ride owners and design reviewers to confirm how this is applied in practice.

The review has focused on two areas of the design review: the structural integrity of the ride and the risk assessment process. Particular attention has been concentrated on the structural aspects, since operating experience has shown these to be the largest current contributor to significant incidents on fairground rides.

A number of key points and recommendations have been raised throughout this report. The key points arising from this review have been assembled in summary form in the Conclusions of this report with respect to the following aspects of the design review.

- Safety Framework
- Design Review
- Structural Fatigue
- Inspection and Maintenance for Fatigue
- Risk Assessment
- Communication

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

The Amusement Device Safety Council (ADSC) has noted the findings of this report carried and is pleased to record that it has already taken positive measures to effectively address a number of the issues raised in this report including the introduction of revised systems and procedures relating to the production of Design Reviews. The ADSC will continue to monitor and review ways in which safety can be further promoted in conjunction with the HSE.

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