Race track modeler. Developing an iterative design workflow combining a game engine and parametric design.

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This paper documents the continuing development and testing of a novel digital work flow established and implemented for the design and redevelopment of formula one racing tracks. The Race Track Modeler (RTM) tool uses a game engine to simulate driving around proposed track designs. Performance data from the simulation is combined with real data acquired from analysis of vehicle mounted accident data recorders (ADRs). The output of the tool is a graphical representation of simulated stopping positions of vehicles that have lost control and left the track. This information directly informs the design of motor racing facilities; the zoning of spectator facilities, position and specification of crash barriers (if required), and surface material selection for the run-off zones (the area where vehicles are expected to stop after losing control and leaving the track). The RTM can suggest further design changes to the track geometry which are then fed back into the game engine. The project involves methods of binding analysis of design directly to geometry together with input from interactive controls. The RTM has been developed and tested during the redevelopment of Silverstone race track in the United Kingdom (figure 1) this paper documents the current state of the tool and concludes with proposed future developments.

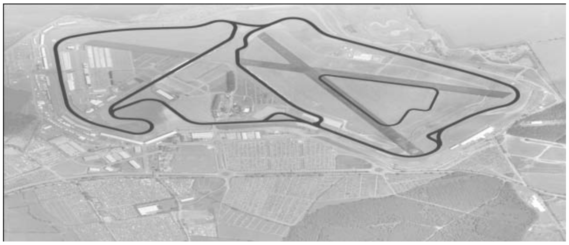

Figure 4. Proposed track at Silverstone.

Introduction: Background to the design of race tracks

In the past the design of race tracks has been dependant on the Fédération Internationale de l'Automobile (FIA) throughout the design process. The FIA generated the speed profiles (estimated speeds of vehicles as they travel around a track) and provided the corresponding trajectories (estimated path of out of control vehicle) over course designs submitted by track designers. The time required to submit a design and receive the FIA generated data was lengthy and this delay stifled innovative design. The ability to make quick changes to the design of the track is thought to lead to safer tracks, more exciting races and better spectator facilitates drawing both bigger crowds and bigger television audiences.

The RTM workflow allows a more flexible and dynamic approach to the design of race track and facilities by allowing more design iterations to take place in house. The authors believe the result of this is a more efficient process to design better racing and spectator facilities, prior to sending to FIA for final approval.

Track safety

One of the primary concerns during the design of a race track is the safety of spectators, drivers and officials on duty. Vehicles competing must be enclosed within a secure boundary. Where this boundary is in close proximity to the edges of the track rigid crash barriers that prevent out of control vehicles leaving the boundary may be required. The need and specification of crash barriers is dependent on predictions made about the path and speed of an out of control vehicle. These predictions determine the direction that the vehicle leaves the track, the rate of deceleration and stopping position. If the run-off zone overlaps the secure perimeter crash barriers are required.

Crashes in Formula One have been studied since 1997 using data collected in vehicle mounted accident data recorders (ADR). Rates of deceleration over different surface types have been deduced from statistical studies undertaken by the FIA. These rates of deceleration form the basis of equations defined by the FIA safety guidelines for calculating vehicle stopping distances. Vehicles are assumed to leave the track at a tangent from the racing line. At regular intervals round the track (as the vehicle speeds vary) an algorithm is used determine the tangent to the racing line, stopping distances and final stopping locations (crash trajectories). The crash trajectory directly informs the design of the track both in terms of barrier specification and spectator zoning. Manually performing this analysis is time consuming and it conflicts with the desire to explore design options. It is this conflict that has led to the development of the RTM.

Use of simulation engine in design

A simulation or game engine is a software system designed for the creation and development of video games. The core functionality typically provided by a game engine includes a rendering engine for 2D or 3D graphics, a physics engine or collision detection (and collision response), sound, scripting, animation, artificial intelligence, networking, streaming, memory management, threading, localization support, and a scene graph. The process of game development is frequently economized by in large part reusing the same game engine to create different games.

Game engines have received recent interest in architecture as a means of collaboration, visualizing design (Pelosi 2010) and reconstruction of historic buildings and landscapes (Tredinnick, Harney 2009). In this paper we describe the use of a game engine to combine human input with simulated data as a core part of a process that informs architectural design.

Use of parametric design

Parametric design involves the use of a computer to automatically modify a design as the values of parameters change and to make corresponding changes to the computer models during the design process (Hudson 2010). Parametric design is the process of developing a computer model or description of a design problem. This representation is based on relationships between objects controlled by variables. The parametric model then forms a part of the design process where the variables are changed and the results examined in order to find better design solutions. In architecture, applications of parametric design involve the determination and control of the geometry of buildings and the definition of manufacturing data.

The RTM is an example where a parametric modeling tool is used to combine the simulated physical data from the game engine with analogue data collected from Formula One race vehicles and a proposed track geometry. Processing this combination of data provides predicted crash trajectories that are imposed on the track layout allowing the designer to visualize the impact of their proposals and respond to them either by:

- Modifying the track.
- Defining and adjusting spectator zones.
- Specifying the construction quality of crash barriers
- Defining the location of crash barriers.
- Varying the racing surface type to influence coefficient of friction.

Workflow: Overview

Figure 2 illustrates the project workflow starting with an initial track design that defines the track edges and racing line geometry. The track geometry is imported into the simulation engine and a professional simulation driver is employed to drive a fastest possible lap. After some practice, lap telemetry is generated and recorded. A speed profile is extracted from the telemetry and together with the racing line and track geometry provides the input to the parametric safety analysis model. The vehicle crash trajectories are then defined. The parametric model also maps vertical track profile and corresponding curvature against the permitted vertical curvature. The results are scrutinized by the architectural design team and their conclusions inform the next design iteration. This may involve returning to the track geometry, developing spectator facilities in zones indicated by the analysis, specification of crash barriers or finalizing design details and preparation of project documentation package which is then sent to the FIA for safety approval.

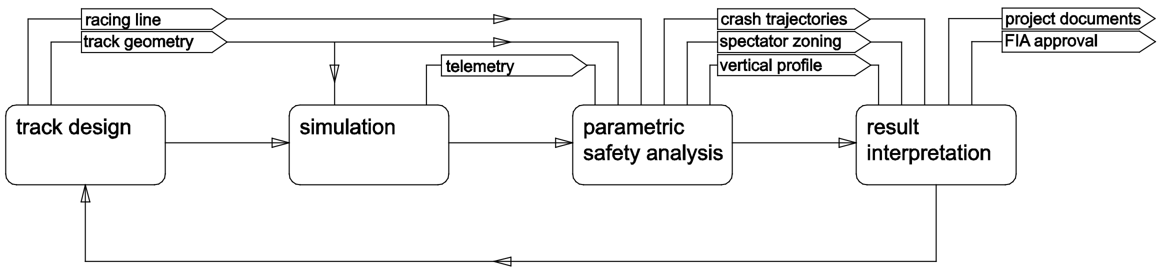

Figure 2. Workflow.

Track geometry

Track design is undertaken at Populous by an expert track designer with 15 years experience in motor sport facility design. His responsibility is to define the race track and racing line. The track and racing line are modeled first in two dimensions using Bentley System's Microstation (Bentley 2010a) and then in three dimensions using GeoPak (Bentley 2010b) to combine the 2D plans with site topography. The track designer's skills are based on experience of both the race vehicles and spectator experience of races. Using this knowledge a racing line is created. A racing line is the path that the vehicle is thought to move fastest round the track. It is known that the racing line will vary depending on the driver and driving style and vehicle setup so its definition is partly subjective. For the RTM it is currently drawn manually by trying to fit the largest radius arc through each corner to minimize loss of speed. Corner arcs are linked together with tangential lines and then converted to a closed bspline curve (figure 3).

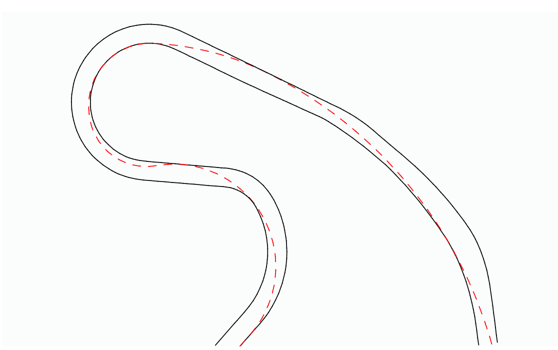

Figure 3. Track geometry through Luffield corner at Silverstone – edges and racing line (shown dotted).

Tangential arc and line geometry defines step changes in curvature at tangents. A race car on the track would actually transition smoothly from straight to corner (continuity of curvature). The curvature continuity achieved with tangent geometry is an approximation which is currently considered sufficient for the purposes of design. The definition of the racing line is discussed again in the further work section.

Implementation of the game engine

From Geopak the proposed track is imported into 3DSMax where using a plugin it can be exported to the game engine Gmotor2 developed by Image Space (2010a). This game engine has been used for simulation in the development of Formula One vehicles, and is used in both commercial and military applications. The rFactor (Image Space 2010b) racing game is based on Gmotor2. The strength of the Gmotor2 engine lies in the vehicle setup configuration which can be tuned to mechanical settings specific to Formula One vehicles. Vehicle set up relates to adjustable parts that would be set on race days in response to weather, driver/rider preference and race track characteristics. Adjustable vehicle parts include shock absorbers and anti-roll bar (suspension), gear ratios and differential, tire pressures and type, wing angles, wheel toe-in and camber angle, brake bias, steering lock and ride height. This degree of user specification makes Gmotor2 popular for Formula One simulations by the racing industry.

The design team pay professional drivers specialized in driving in simulated environments. Vehicle setup is configured using data from Formula One vehicles currently in use, in addition the driver can then make further adjustments according to their preferences. The driver sits on a Formula One seat within a monocoque chassis with force feedback steering wheel and pedals (figure 4).

Figure 4. Example of set up for driving on simulated track.

The race simulation is either projected onto a screen or displayed on monitors. After several practice laps the telemetry is analyzed and further attempts are made at fastest lap. At this point the driving team has the option of using the racing line defined by the driver along with the game engine's artificial intelligence algorithms to try and drive a faster lap. Telemetry readings are taken at specific time intervals and provide the vehicle speed and position around track. This data is stored as a comma separated value (CSV) file and imported to excel. The speed profile for the redesigned Silverstone track is shown second from the top with other telemetry in figure 5.

Parametric model

Parametric safety analysis is undertaken with Bentley Systems' GenerativeComponents (Bentley 2010c). Four referenced files as inputs are required, three drawing files in the Microstation dgn format and an excel file with the speed profile data. The drawing files define the track edges, racing line and zones of gravel beds all as bspline curves, in addition the track edge file must contain a short line representing the start line.

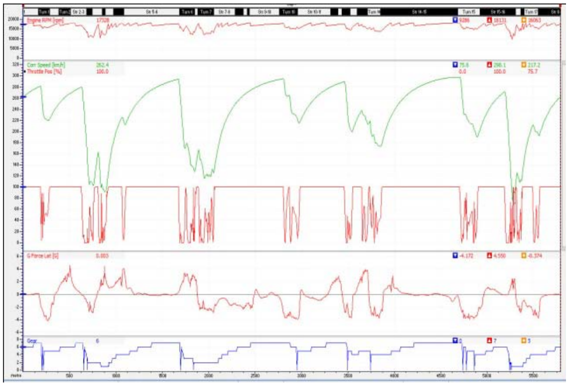

Figure 5. Telemetry from Gmotor2/rFactor for the redesigned Silverstone track.

The user has to ensure the files are in the correct format and are present in a folder with the RTM GenerativeComponents script file. The script file can then be opened and the user then steps through a series of transactions defined by the script. This sequence of transactions imports the track and racing line geometry and reads the speed data. Lastly the trajectory generator algorithm combines the referenced geometry and the speed data to produce all crash trajectories around the track (figure 6).

The user can manipulate a series of input parameters that define the deceleration coefficients for asphalt and gravel, gravity, a constant k and the direction around the track. The constant k is a value that has been found from analysis of the accident data recorders and relates the deceleration coefficients to current vehicle specification. Input parameters are initially set to default values to allow the designer to focus on the track.

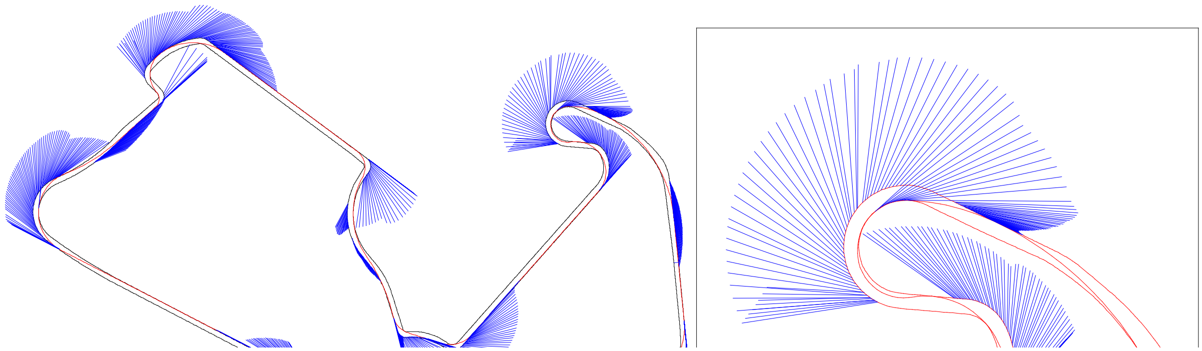

Figure 6. Track with crash trajectories.

When trajectory generator algorithm is executed the RTM creates deceleration curves as a graphical look up tool (figure 7). These are based on data from the ADRs which define equations that relate speed to stopping distance for a particular surface. The stop curves for gravel and asphalt are shown in figure 7 and key points used in calculation of one crash trajectory are shown in figure 8. Figures 7 and 8 should be read in conjunction with the algorithm diagram in figure 9.

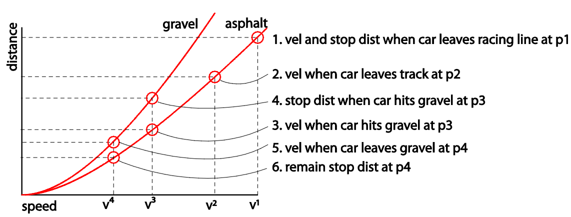

Figure 7. Deceleration curves for gravel and asphalt.

Counter to intuition, stopping distances on gravel surfaces are greater on asphalt, this is due reduced friction as the vehicle slides over the rougher looser surface. The dotted lines on the deceleration curves in figure 7 illustrate the steps that the trajectory generator algorithm executes until the vehicle's final stop position is found.

The RTM allows the designer to interrogate an individual crash trajectory to find the speed of the out of control vehicle at any distance as it moves away from the racing line (figure 10). If a crash barrier is required the anticipated speed of the vehicle as it hits it is used to specify the barrier construction.

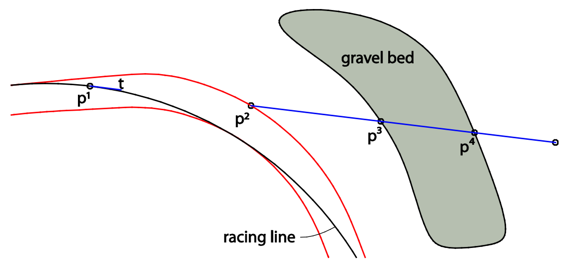

Figure 8. Key points for crash trajectory calculation.

Application

The RTM tool was used extensively on the redesign of Silverstone in the UK (figures 1 and 11). Approaching the design of a racing facility in this way is novel for the domain. This approach is closely aligned with the design of the vehicles where simulation plays a significant part. Developing a new design tool using a current project as a test case forces a degree of focus that cannot be obtained in a hypothetical scenario. The success of the tool is in its continued use throughout the project, and by the positive response of Formula One drivers that raced the British Grand Prix in 2010. Application of the RTM to the Silverstone project highlighted the need for additional functions such as the trajectory interrogator (figure 10). The modular design of the RTM allowed for this type of modification.

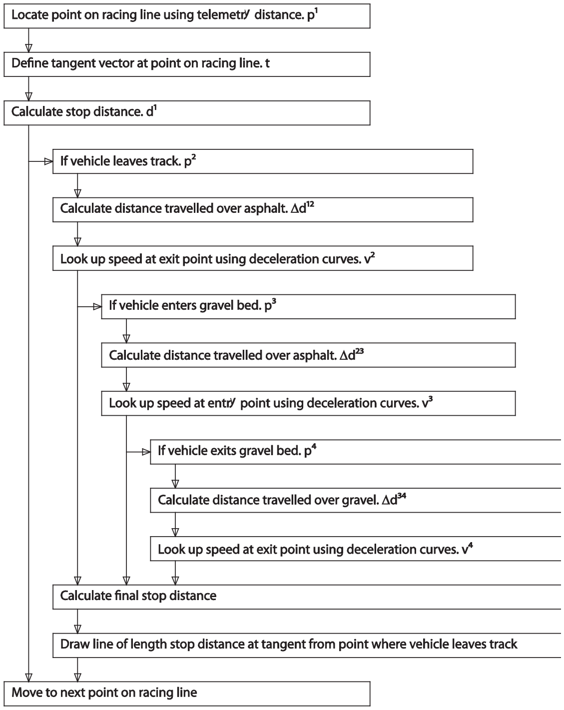

Figure 9. Trajectory generator algorithm.

The development team was small and consisted of a CAD manager, expert designer and parametric modeler. The size of the team meant it was simple to establish a common language required for the naming of variables in the application and for discussions during development and initial use.

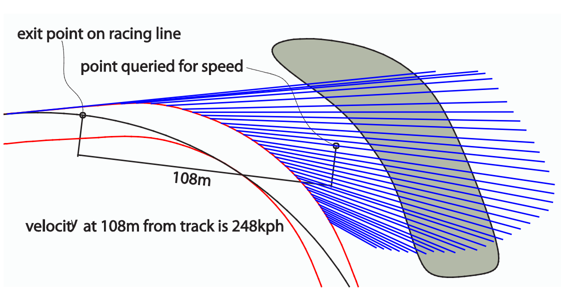

Figure 10. Interrogating a crash trajectory for vehicle velocity at a specific distance from the racing line.

The small team working on Silverstone required clear definition of responsibilities in terms of tool management with the practice and tool maintenance. The tool specification was supplied by the expert designer who was also the primary user, this meant no training or training manuals were necessary. In a situation with a larger user group the need to specify responsibilities and provide training and documentation would be necessary.

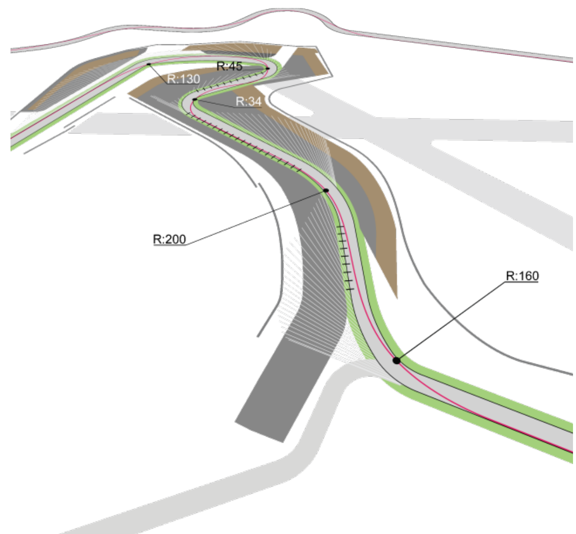

Figure 11. Data produced for Silverstone redesign.

Future work

Currently work is under way for further development of functions for analysis of the vertical profile of the track (figure 13). The FIA specify guidelines to determine maximum radius in relation to vehicle velocity. Two equations are given to accommodate convex and concave profiles. At this point the RTM includes a rudimentary system that provides graphical comparison linking vehicle speed (dashed), proposed track profile (dotted), proposed track curvature (solid) and permitted curvature (dash dot) (figure 12). The comparison enables the designer to see when proposed curvature exceeds permitted or where there are opportunities for increasing proposed curvature. These zones can be identified from the comparison graphic. Areas exceeding permitted curvature are where the solid curve (proposed curvature) is above the dash-dot curve (permitted curvature). Further effort is required to provide

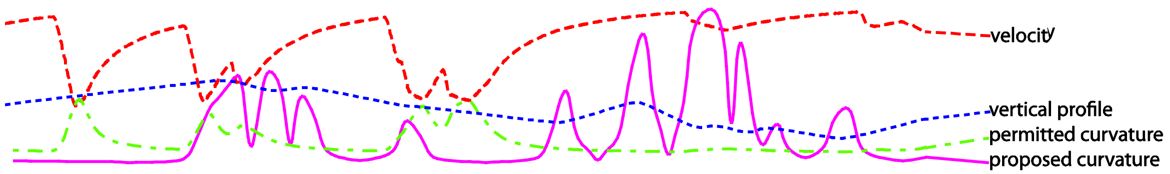

Figure 12. Comparison of permitted and proposed vertical curvature.

interactive control so the designer can manipulate the track profile in response to the analytic comparison.

Future work yet to be addressed will investigate the development of algorithms for determining racing line through the track by minimizing curvature. As the definition of the racing line requires expert knowledge the curve generated will require interactive control to allow the designer to provide further input. One possible avenue of exploration is the use of evolutionary design.

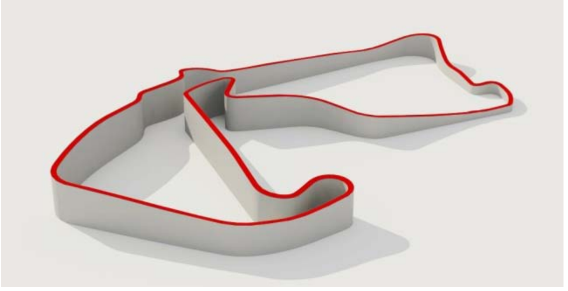

Figure 13. Vertical profile of track.

Conclusions

The Race Track Modeler tool allows Populous to rapidly assess many design iterations and track proposals before sending to FIA. Designs are now sent to FIA for approval and not design assistance and subsequently more design alternatives can be investigated.

The architectural implications of this process may not seem obvious however; the tool has been developed by architects for architects. It is the latest in a series of design decision support mechanisms developed for Populous. Earlier tools include a stadium seating bowl design and analysis tool (Hudson 2010) and a custom tool for developing geometry, cladding, structure and coordinating construction for an international rugby stadium (Hudson 2008, Shepherd and Hudson 2007). The use of parametric design in this context is primarily concerned with developing tools for expert designers which aim to formalize expert knowledge and experience. In contemporary architectural design practice this is a growing area of specialization. Working in a mixed parametric mode, part algorithmic and part expert knowledge has come about due to several reasons: availability of customizable tools, increasing specialization of design task and individuals in industry with skills in design and algorithmic methods.

The authors make the following recommendations for engaging in this kind of process.

- Develop a logical common language for variable and object naming.
- Develop the model in a modular or fragmented way to simplify extension and changes.
- Establish who is going to use the tool and what their skill levels are.
- Develop default parameter sets.
- Establish who is responsible for maintaining the tool.
- Establish who is responsible for managing the tool within the practice.
- Allocate time for developing a user manual and documentation.
- Allocate time for training users.
- Allocate time for modification following training.
- Anticipate longer term (on-going) support

The notion of binding analytic data directly to geometric objects is at the core of this paper. This kind of data visualization presents new opportunities for architectural design processes some of which have been explored by Peters and DeKestiler (2006) and Dritsas and Rafailaki (2007). Further work is required to investigate methods and possibilities obtained when dynamic interactive control is embedded with design analysis.

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