Time savings by using a BIM workflow in roundabout design

Executive Summary

This paper written by Savoy Computing, authors of AutoTrack, compares the traditional roundabout design workflow with the new BIM workflow possible using AutoTrack, ARCADY and AutoCAD Civil 3D. Specifically, it looks at the time taken in the various stages involved in creating a 3D roundabout design and subsequently to make changes to that design.

The paper concludes that the BIM solution has substantial benefits in terms of time, cost and accuracy over traditional methods. Furthermore, it clearly shows that the benefits escalate rapidly both as the model is extended to include more of the design process, and over the project life cycle.

The results show that it can be up to five times faster to create the initial model but that, using the full implementation of AutoTrack, ARCADY and Civil 3D, changes can be made and checked in real-time, equivalent to a speed improvement of around 800 times.

"At its best, the BIM workflow with real-time data links condenses an 84 minute design iteration time into a mouse move with near instant update! This means that, in future, you will know before you've even finished the edit what further changes may (or may not!) be required."

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Introduction

Roundabout design is a highly iterative process; designers must balance the demands of compliance with geometric guidelines, provision of acceptable vehicle capacities, management of safety by controlling vehicle speed and sightlines, suitability for appropriate design vehicles and finally, the practical considerations of construction within geographic and financial constraints. Often each of these considerations is managed by a different specialist team. As a result, traditionally roundabout design is a lengthy process wherein the design moves between disciplines until all are happy.

Within each area of design computers are already used extensively; the problem is that the programs don't work together or share data and therefore the process is fragmented and requires repeated measurement and re-entry of data as it changes. The traditional system results in a multiplicity of computer files, each of which has no direct link to the others. Recently Savoy Computing in collaboration with the UK's Transport Research Laboratory (TRL) and Autodesk have developed a system based on BIM (Building Information Modelling) methodologies that could offer significant time savings by speeding up the design iteration cycle time. This speed improvement should make it possible for design teams to consider more options and thereby produce even more appropriate solutions.

This document is a detailed comparison of the traditional method versus the new tools and ultimately the BIM workflow with particular reference to the time taken. We will be considering a typical four arm roundabout. In the interests of fairness we have assumed what we believe are nominal times for each of the tasks listed. We believe these times are conservative and would be unachievable in all but the simplest circumstances. However, throughout the document we invite you to note down the time it takes you to perform each task using your current workflow and we would be very grateful if you could send us a copy to allow us to improve the accuracy of our data.

Roundabout Design Process

Creating safe and efficient roundabouts can be split into any number of discrete stages but, for the purposes of this document we will consider the following stages which map conveniently onto the three tools that make up the new system:-

1. Creation of 2D geometry (AutoTrack)
2. Analysis of flow/capacity, traffic performance & accident probability (ARCADY)
3. Creation of 3D ground model (AutoCAD Civil 3D)
4. Design iterations and fine-tuning of 3D model (All)

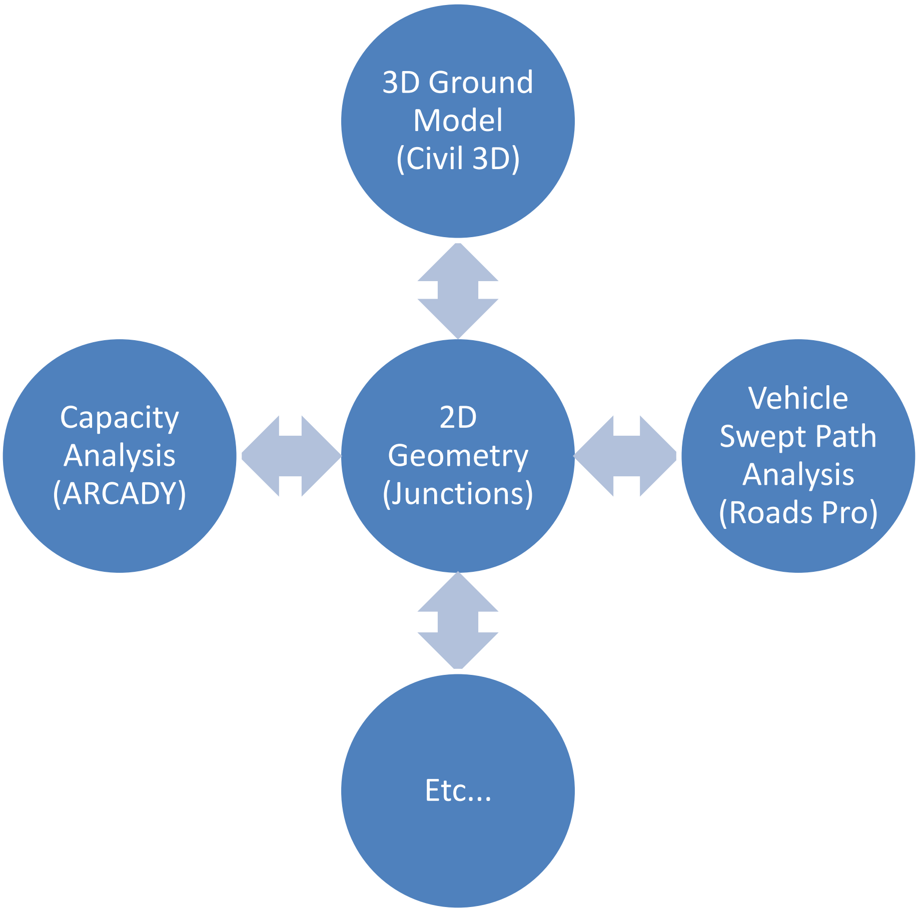
Clearly there are additional tasks such as creating signage and road markings but for now let's limit our investigations to the above four stages.

Each of these stages is not only iterative with the others but within itself. We will consider the tasks involved in each of these stages and how the traditional methods compare with new BIM workflow.

Integrated Workflow in Outline

The key to the AutoTrack based system is that it manages to link together the disparate aspects of roundabout design so that the engineer ends up building and working with a single shared 3D data model.

The core of the model is AutoTrack which provides the basic 2D geometric data to the other components of the system. The other elements receive this data and pass data back to the 2D model where necessary.



In order to make a sensible comparison of the time savings possible using the new system over traditional methods we will compare the workflow for both the initial creation of the model and the workflow of subsequent editing operations.

Creation of 2D roundabout geometry

Most national standards specify how to create the roundabout geometry. The task for the engineer is then to follow these rules and construct the geometry using CAD tools or manually. The process is generally as follow:-

1. Place a suitably sized roundabout, island and apron.
2. Place approach road centrelines
3. Create offside definition lines (taking into account any centre gap required)
4. Create nearside definition lines
5. Place splitter islands (if required)
6. Create nearside kerbs (often coincident with definition lines)
7. Place pedestrian crossings on each arm (if required)

There are often simple geometric rules that must be checked such as a requirement for the circulatory width to accommodate specific design vehicles. This involves:-

8. Measurement of the circulatory width and check against design vehicles.

There will also be safety requirements intended to control visibility and speed and thereby minimise the risk of collisions. These requirements normally include checks of the path radii (which determine the speeds) of vehicles entering, circulating and exiting the roundabout. To check these radii the engineer must:-

9. Construct the fastest vehicle paths from each entry to every exit (this is a relatively complicated construction that is defined quite well by some standards and not at all by others).
10. Construct the conflict angles and entry deflection.

The requirements also often include a check of sightlines at various points on the roundabout and approaches. There may be several sightlines for each arm. This again requires the engineer to:-

11. Construct the sightlines for each arm and for the circulatory area.

There are often also checks for vehicle access for which the engineer must:-

12. Place actual vehicle paths in lanes for path overlap checks.

Note that the adjustment for any failure to meet design criteria falls under the design iterations process later in this document.

Traditional method vs. the new workflow

The time taken for the above tasks using traditional methods will vary according to the experience of the engineer and his CAD skills but we have assumed that conservatively each task will take one minute for each arm. Using the new workflow, AutoTrack Junctions manages the creation of the roundabout geometry to maintain compliance with the requirements of the selected standard. It creates a fully compliant default roundabout with just a few mouse clicks. Of course, typically the engineer still needs to edit the dimensions to suit his needs but as he edits them the related geometry is automatically updated. So, for example, if he adjusts the centre island diameter, AutoTrack Junctions automatically adjusts the offside definition lines, the nearside definition lines, the splitter islands and any pedestrian crossings (tasks 3, 4, 5, 6 & 7 above) instantly.

Creation of default 2D roundabout geometry	**Traditional**	**BIM**	**You!**
Place centre island, inscribed circle and (if required) the apron	1 min	20 sec	
Calculate and draw the alignments for all arms	4 x 1 min	4 x 10 sec	
Calculate and draw the offside definition lines for all arms	4 x 1 min	<< 1 sec	
Calculate and draw the nearside definition lines for all arms	4 x 1 min	<< 1 sec	
Calculate and draw the nearside and inter-arm kerb for all arms	4 x 1 min	<< 1 sec	
Calculate and draw the splitter definition lines for all arms	4 x 1 min	<< 1 sec	
Calculate and draw any splitter islands for all arms	4 x 1 min	<< 1 sec	
Calculate and draw any pedestrian crossings for all arms	4 x 1 min	<< 1 sec	
Calculate and draw the conflict angles for all arms	4 x 1 min	<< 1 sec	
Calculate and draw the fastest paths for all arms to every other arm	4 x 1 min	<< 1 sec	
Measure the smallest radius for entry, circulating, exit, left & right turn for all arms	4 x 1 min	<< 1 sec	
Calculate the speed that corresponds to the smallest path radii for all arms	4 x 1 min	<< 1 sec	
Check critical path radii and speeds against standards for all arms	4 x 1 min	<< 1 sec	
Calculate, draw and check all sightlines for all arms	4 x 1 min	<<1 sec	
Check all geometric values against standards for all arms	4 x 1 min	<< 1 sec	
*Check design vehicle swept paths for all arms	4 x 1 min	<< 1 sec	
Total for creation of 2D roundabout geometry	**61 min**	**~1 min**	

All tasks require AutoTrack Junctions except those marked * which require AutoTrack Roads Pro

Results

The speed improvements in using Junctions to create just the 2D model with no analysis or 3D model is therefore 61/~1=61. To also analyse and this and create the 3D model but without the dynamic data links this drops to:-

$$\text{Speed improvement} = \frac{(61+16+17)}{(1+16+17)} = 2.7 \text{ times faster!}$$

Note that these benefits are achievable using AutoTrack running stand-alone without ARCADY and without a CAD system.

Analysis of Vehicle Capacity & Accident Probability

Once we have a roundabout that complies with geometric guidelines we need to check that it can handle the required traffic flows with acceptable delays and that the predicted accident rates are tolerable. This is normally assessed using a program like the industry standard ARCADY. (N.B. Use of ARCADY is mandatory in the UK). The process is as follows:-

1. Measure the values required by ARCADY for all arms
2. Create a new ARCADY model
3. Enter arm geometry for all arms
4. Enter pedestrian crossings (if required) for all arms
5. Enter predicted or collected vehicle turn data
6. Enter vehicle type proportions

Traditional method vs. the new workflow

In the traditional design process, the capacity analysis is often carried out by a different team. They must measure key dimensions of the roundabout geometry (sometimes by simply scaling from hardcopy) and use them to build an ARCADY model. They may also need to add details of pedestrian crossings, enter traffic flow data and vehicle mix factors before running the analysis. In the new workflow, the ARCADY model is created automatically, based upon geometry passed to it by AutoTrack Junctions. This is not only a significant time saving (replacing, as it does, tasks 1 to 4 in the above list) but results in greater consistency of measurement, improved accuracy and less risk of errors. Of course, the traffic flows and other analysis criteria must still be entered manually.

Traffic capacity analysis	Traditional	BIM	You!
Measure the values required by ARCADY for all arms	4 x 1 min	<< 1 sec	
Run ARCADY and create a new roundabout model	1 min	<< 1 sec	
Enter arm geometry for all arms	4 x 1 min	<< 1 sec	
Enter pedestrian crossings (if required) for all arms	1 min	<< 1 sec	
Enter predicted or collected vehicle turn data	4 x 1min	4 x 1min	
Enter vehicle type proportions	1 min	1 min	
Run analysis	<< 1 sec	<< 1 sec	
Total for creation of roundabout analysis model	**16 min**	**5 min**	

Results

The speed improvements using AutoTrack and ARCADY linked to simply create and analyse the 2D roundabout are therefore (61+16)/(1+5)= 12.8 but assuming you still need to construct the 3D model (using traditional methods) this drops to:-

$$\text{Speed improvement} = \frac{(61+16+17)}{(1+5+17)} = 4.1 \text{ times faster!}$$

Note that these benefits are achievable using AutoTrack linked to ARCADY.

Construction of the 3D roundabout model

The conversion of the 2D model into a 3D roundabout model involves the creation of surface profiles and cross section assemblies which together are used to build a 3D model road of each arm of the roundabout and the roundabout itself. The actual process may vary in detail according to the tools used and the preferred method working. However, the recommended process using AutoCAD Civil 3D is as follows:-

1. Create horizontal alignments for the nearside and offside road definition lines for each arm.
2. Create horizontal alignments for the ICD and the island.
3. Create vertical profiles along the nearside and offside alignments for each arm.
4. Create vertical profiles along the ICD and island alignments
5. Create the cross sections (assemblies) for the arms and the roundabout itself.
6. Build the corridor with one region for each arm and another for the circulatory area.
7. Surface the corridor.

Traditional method vs. the new workflow

Again, the time for the above tasks using traditional methods will vary according to the experience of the engineer but we can safely assume that it will take in the order of 15 minutes. Using the new workflow, AutoTrack Junctions creates the horizontal alignments automatically when the roundabout is created – that's tasks 1 & 2 in the above list!

Creation of 3D ground model	Traditional	BIM	You!
Create alignments on the nearside & offside kerbs for all arms	4 x 1min	<< 1 sec	
Create alignments on the island and inscribed circle	1 min	<< 1 sec	
Calculate the vertical profiles on the alignments for all arms	4 x 1min	4 x 1 min	
Calculate the vertical profiles on the alignments for the island and inscribed circle	1 min	1 min	
Create the cross section assemblies for the arms and roundabout	1 min	1 min	
Create and surface the corridor	5 min	5 min	
Total for creation of 3D roundabout model	**17 min**	**11 min**	

Results

The speed improvements for the creation and analysis of the full 3D model are therefore approximately:-

$$\text{Speed improvement} = \frac{(61+16+17)}{(1+5+11)} = 5.5 \text{ times faster!}$$

Note that these benefits are achievable using AutoTrack running in AutoCAD Civil 3D with ARCADY.

Design Iterations

It would be an unusual roundabout that was not subject to change after the design had been 'completed'. Unfortunately, almost any change in a roundabout design means that virtually every task must be repeated.

Traditional method vs. the new workflow

Once all elements on the model have been created the savings 'per iteration' become much more significant. In the traditional workflow, any change in any aspect of the model requires that almost every task and check be repeated. In the new BIM workflow, the data is all linked dynamically so, when a value changes, the rest of the model updates automatically. This results in such a colossal time-saving that it is possible to monitor the effects of changes in real-time.

Rough timings for the recreation if the 2D geometry after moving the roundabout are as follows:-

Design iterations	Traditional	BIM	You!
Recreation of 2D roundabout geometry			
Recalculate centre island, inscribed circle and (if required) the apron	1 min	<< 1 sec	
Recalculate the alignments for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw the offside definition lines for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw the nearside definition lines for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw the nearside and inter-arm kerbs for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw the splitter definition lines for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw any splitter islands for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw any pedestrian crossings for all arms	4 x 1 min	<< 1 sec	
Recalculate, redraw and check the conflict angles for all arms	4 x 1 min	<< 1 sec	
Recalculate and redraw the fastest paths for all arms to every other arm	4 x 1 min	<< 1 sec	
Measure the smallest radius for entry, circulating, exit, left & right turn for all arms	4 x 1 min	<< 1 sec	
Recalculate the speed that corresponds to the smallest path radii for all arms	4 x 1 min	<< 1 sec	
Recheck critical path radii and speeds against standards for all arms	4 x 1 min	<< 1 sec	
Recalculate, redraw and recheck all sightlines for all arms	4 x 1 min	<<1 sec	
Recheck all geometric values against standards for all arms	4 x 1 min	<< 1 sec	
Recheck design vehicles swept paths for all arms	4 x 1 min	<< 1 sec	
Total for recreation of 2D roundabout geometry	**61 min**	**< 1 sec**	

Rough timings for rechecking the analysis after moving the roundabout are as follows:-

Design iterations	Traditional	BIM	You!
Recheck traffic capacity analysis			
Measure the values required by ARCADY for all arms	4 x 1 min	<< 1 sec	
Update arm geometry for all arms	4 x 1 min	<< 1 sec	
Total for analysis of 2D model	**8 min**	**< 1 sec**	

Rough timings for the recreation if the 3D geometry after moving the roundabout are as follows:-

Design iterations	Traditional	BIM	You!
Recreation of 3D ground model			
Create/adjust alignments on the nearside & offside kerbs for all arms	4 x 1min	<< 1 sec	
Create/adjust alignments on the island and inscribed circle	1 min	<< 1 sec	
Calculate/adjust the vertical profiles on the alignments for all arms	4 x 1min	~1 sec	
Calculate/adjust the vertical profiles on the alignments for the island and inscribed circle	1 min	~1 sec	
Create/update and surface the corridor	5 min	~6 sec	
Total for recreation of 3D model	**15 min**	**~8 sec**	

Results

The speed improvements in editing the model are therefore approximately as follows:-

$$\text{Using AutoTrack alone} = \frac{(61+8+15)}{(8+15)} = 3.6 \text{ times faster!}$$

$$\text{Using AutoTrack \& ARCADY} = \frac{(61+8+15)}{15} = 5.6 \text{ times faster!}$$

$$\text{Using AutoTrack \& ARCADY in Civil 3D} = \frac{(61+8+15)}{0.1} = 840 \text{ times faster!}$$

Note there are further benefits available by running in AutoCAD Civil 3D that have not been considered here, such as the automatic recalculation of cut and fill, mass haul analyses, surface drainage, and so forth.

Results

The table below lists the speed improvements for different design scenarios based upon the preceding figures. These are calculated using the following equation:-

$$\text{Speed Improvement} = \frac{Time\ for\ tasks\ \text{all}\ using\ traditional\ method}{Times\ \text{for}\ BIM\ tasks + Time\ for\ traditonal\ tasks}$$

Note that we have listed times for the creation of a roundabout with no analysis even though this is unlikely to be permitted.

We have highlighted the figures that relate to the most likely scenario, the creation and analysis of a 3D roundabout model.

Requirement	Speed Improvement	
	Creation	Design Iterations
2D roundabout without analysis		
Using AutoTrack	$\frac{61}{1} = 61$	$\frac{(61+8)}{(0.01)} = 6100$
2D roundabout with analysis		
Using AutoTrack and another analysis system	$\frac{(61+16)}{(1+16)} = 4.5$	$\frac{(61+8)}{(8)} = 8.6$
Using AutoTrack & ARCADY linked	$\frac{(61+16)}{(1+5)} = 12.8$	$\frac{(61+8)}{0.1} = 690$
3D roundabout without analysis		
Using AutoTrack and another ground modelling system	$\frac{(61+17)}{(1+17)} = 4.3$	$\frac{(61+15)}{(0.01+15)} = 5.1$
Using AutoTrack and Civil 3D	$\frac{(61+17)}{(1+11)} = 6.5$	$\frac{(61+15)}{(0.01+0.1)} = 760$
3D roundabout with analysis		
Using AutoTrack with another analysis system and another ground modelling system	$\frac{(61+16+17)}{(1+16+17)} = 2.7$	$\frac{(61+8+15)}{(8+15)} = 3.6$
Using AutoTrack & ARCADY linked but another system for the ground model	$\frac{(61+16+17)}{(1+5+17)} = 4.1$	$\frac{(61+8+15)}{15} = 5.6$
Using AutoTrack, ARCADY & Civil 3D to create and analyse a full 3D roundabout model	$\frac{(61+16+17)}{(1+5+11)} = 5.5$	$\frac{(61+8+15)}{(0.1)} = 840$

Conclusions

Firstly, a word of caution about the times quoted for the various tasks using the traditional workflow. Not only are they approximations but they are also very dependent on individual skill levels and experience. However, although they are only estimates, they are based on conservative times for the traditional workflow (or so we believe) and therefore we can assume that these are **minimum** achievable productivity gains. In fact, because the traditional workflow often involves different teams, the elapsed time taken for some of these tasks may run into days, or even weeks, much less minutes!

That said, the results clearly demonstrate the benefits of using the fundamental BIM principle of data sharing and show an increased in the value of the model over the project life cycle, i.e. the gains are less marked (though still significant) during the creation of the model but very significant once the model is built. This means that the system is ideally suited to assessment of alternative design options. The data also show how the time savings escalate as one extends the BIM model from AutoTrack to ARCADY and into Civil 3D.

Of course, this new workflow does raise the question... ‘Is it reasonable for one designer to handle both the geometric and analytical elements of the design?’. This is really a matter for individual organisations to decide. However, we would argue that, as long as the various disciplines are involved at the initial design stage to define acceptable boundaries and at the final approval stage, in between there is no reason why a competent engineer should not be able to use this system to consider possible alternatives. We would be interested in your views.

Help us improve our estimates

This technology is evolving and whilst it is clear there are significant productivity gains to be had from the use of BIM methodologies we would very much like to refine our figures and improve our estimates of the quantifiable benefit. Please help us by sharing with us how long your existing workflow takes for some or all of the tasks listed. Also, do let us know if we have omitted any tasks.

More Information

Savoy, TRL and Autodesk have developed a site devoted to the use of BIM techniques in roundabout design. You may like to visit it at www.BimRoundaboutDesign.com .

For more information on the products mentioned please visit the websites below:-

www.savoy.co.uk www.trlsoftware.co.uk www.autodesk.com