Throughput of Factorio Train Junctions
a statistical analysis

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For school, somehow

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Contents

1 Background

> Factorio is a game in which you build and maintain factories.
> You will be mining resources, researching technologies, building infrastructure, automating production and fighting enemies. Use your imagination to design your factory, combine simple elements into ingenious structures, apply management skills to keep it working and finally protect it from the creatures who don't really like you.
>
> –*The Factorio webpage[1]*

An integral part of the video game Factorio (on Steam early access since 2016) is the logistics of moving large amounts of material around, which is, much like in real life, often done by train. Like every other aspect of the game, the layout of the rail network is subject to online debate, to find optimal designs. One long standing debate concerns the design of intersections. In one camp, roundabouts are considered the optimal way to arrange an intersection. Others swear to the efficiency of four-way junctions, and others still prefer separating the intersection into two separate T-junctions.

The decision to choose one design over another can rest on many different aspects: Aesthetics, availability for manual navigation, possibility (or possibly risk) of use as turning point, similarity to the road network you navigate in real life and raw material cost of construction are some things that may be taken into consideration. This report is however only focused on one characteristic: The train throughput, i.e. how many trains can pass through the intersection per unit time. This metric is very important for large scale bases, where an intersection can easily become the bottleneck of the entire production chain.

The aim was to compare a number of different designs with regards to throughput, and then to see whether the result is indicative of which general layout is more suitable.

2 Method

2.1 Experimental set-up

Six trains were used to simulate a busy intersection, in accordance with Figure 1. This means each possible route in and out of each station was regularly attempted.

Approximately 500 observations were made for every design.

2.1.1 Game

All experiments were performed in Factorio version 0.15, creative mode. During the measurements, game speed was set to 10x normal speed, in order to reduce lab time. Logging was done using the very helpful mod "CircuitLogger" by Michal Novotny [2].

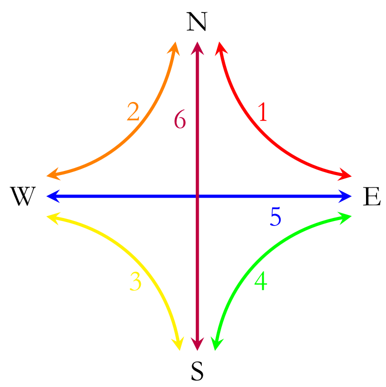

Figure 1: The six possible routes through a four way intersection

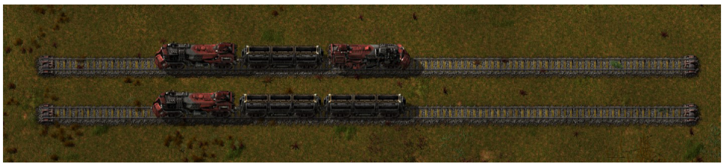

Figure 2: 1-1-1 train (above) and 1-2 train (below)

2.1.2 Trains

The trains used in this experiment were so-called 1-1-1 trains, with one locomotive pointing each direction, on either side of a cargo wagon. While not very common in large scale bases, this set-up allows the trains to reverse at the stations, simplifying their design, and makes the measurements indicative of the more common 1-2 trains (locomotive pulling two cargo wagons), as they are the same length. See Figure 2

The locomotives were fuelled with Rocket Fuel, to near-enough eliminate the need for refueling. This affects their speed, but by an equal amount which means the comparative measurement shouldn't be affected.

Each train was given a unique "signature", in the form of a single item placed in its inventory. There was an iron ore train, a copper ore train etc.

2.1.3 Stations

In order to eliminate risk of blockage, each destination needed at least three stations, to allow all three trains to visit simultaneously.

To make these stations equally distant from the intersection, removing systematic error, they were placed at one end each of a two-level bifurcation. See Figure 3.

The four destinations were named after the cardinal directions, **E**, **N**, **W**, **S**, and each (sub-)station was for completeness given a number 1 to 4.

Figure 3: The station design

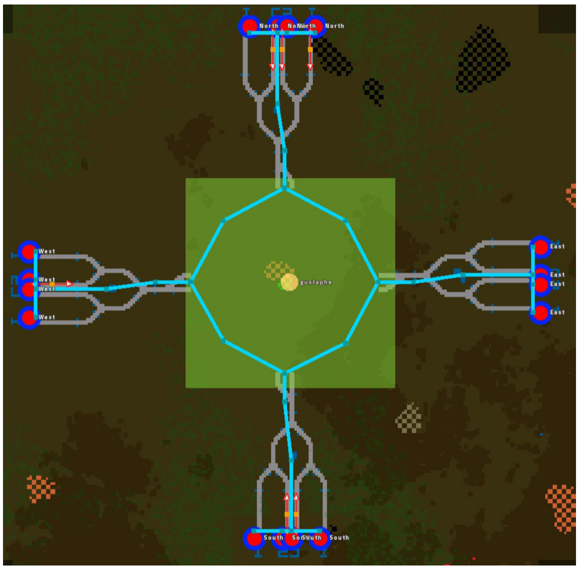

Figure 4: Map of the experimental set-up

2.1.4 Measuring apparatus

The circuitlogger is an item which, at each tick ($\approx 1/60$ game second) checks if any of its signals have changed. If any circuitlogger registers a change, the current signals in each of them is logged in a .csv file, along with a time stamp.

At each destination, a circuitlogger was connected by wire to the first station, and then to the rest of the stations in turn, alternated by combinators adding 1 to each signal, so that a train with 1 iron ore parked at station 4 and a train with 1 copper ore parked at station 2 will result in a signal of 4 iron ore and 2 copper ore being logged.

For each of the signatures, if it changes from > 0 to $= 0$, it begins a journey at that tick. In the same way, if a signature changes from $= 0$ to > 0, that is the tick at which it arrives. Using this information together with the name of the logger which registered each change, an entry can be made into the final data table, consisting of a **passage time** (numeric), **origin** and **arrival destination** (E/N/W/S), **direction** (Left/Right/Forward) and **intersection design**.

2.1.5 Intersection designs

The designs were chosen through scouring the forums[3], Youtube and the Internet in general for popular or interesting blueprints, and then rebuilding them to fit the experimental set-up. Changes had to be made to the signalling of several of the designs, due in part to differences in signalling practices and in part to inconsistency in handedness. All designs were reformatted into drive-on-the-right, the real life de-facto

Table 1: Intersection designs examined in the experiment

Design	Designer	Type	Figure
A	Drizznarte [4]	Crossing	5
B	Mehve [5]	Roundabout	6
C	Tnarg [6]	Roundabout	7
D	Rakkfalen [7]	Crossing	8
E	Self-defeating [8]	Crossing	9

universal standard for car (if not rail) traffic.

All tried intersections were 2 lane designs, which appears to be the most common outside of megabases.

No double-T-junction was included, as it is too dissimilar to the other layouts for accurate comparison. Its asymmetry made analysis too complicated, and it would have been hard to incorporate it in a way that corresponds to how it's used in the field.

2.2 Model

The throughput of an intersection design was approximated as the inverse of the mean passage time. The passage time was assumed to be normally distributed around a real characteristic passage time, with an unknown variance.

Affecting factors are assumed to be **Design**, **Turn direction** (A left turn, for instance, is almost always a further distance than a right one) **Origin** and **Destination** (because of possible internal precedence rules).

An ANOVA was conducted to determine the significance of each of these factors, after which some of the most significant factors were compared using pairwise t-tests. For a sanity check, the normality of the data was checked using Q-Q plots.

2.2.1 Hypotheses

For comparing directions, 3 null hypotheses were formed: H_{0RF}, H_{0RL}, H_{0FL} each corresponding to the directions having equal throughputs.

Departure and arrival destinations were examined using the 12 null hypotheses $H_{0Djk}, H_{0Ajk}, j < k,\ j,k \in \{\text{E, N, W, S}\}$.

For designs, 10 null hypotheses were formed: $H_{0jk}, j < k,\ j,k \in \{\text{A} - \text{E}\}$. Each represents the notion that design j has a throughput equal to that of design k.

The general design types were compared, forming H_0: roundabouts are equal to crossings.

Finally, the most interesting designs were compared direction by direction, evaluating the null hypotheses $H_{0djk}, d \in \{\text{F, L, R}\},\ j < k,\ j,k \in \{\text{A} - \text{E}\}$, corresponding to the throughput of design j turning in direction d being equal to the throughput of design k turning in direction d.

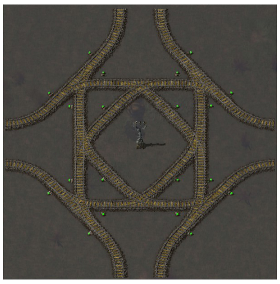

Figure 5: Drizznarte's four-way crossing (A)

Figure 6: Mehve's roundabout (B)

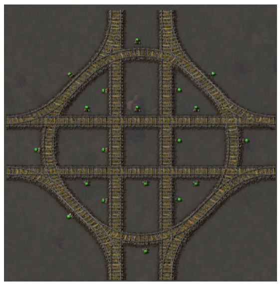

Figure 7: Tnarg's roundabout (C)

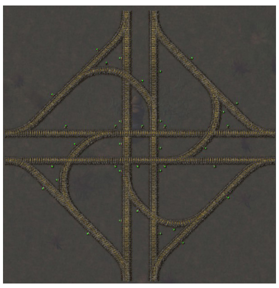

Figure 8: Rakkfalen's spiral junction (D)

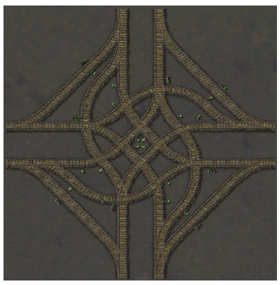

Figure 9: Self-defeating's celtic knot (E)

3 Results

Table 2 shows the effect of direction on passage time. All three combinations of pairwise t-tests returned $p < 1\,\%$. Thus H_{0RF}, H_{0RL} and H_{0FL} were rejected.

Pairwise t-tests with regards to origin return the significant $(p < 1\,\%)$ differences between N and the other three values, but not between them, indicating that journeys starting at N take significantly longer than other journeys, which cannot be internally ordered.

Similarly, journeys with N as destination take significantly shorter than other journeys. H_{0DEN}, H_{0DNW}, H_{0DNS}, H_{0AEN}, H_{0ANW} and H_{0ANS} were rejected.

Table 3, together with Table 4, shows the comparison between different intersection designs. A "Y" at (j, k) in Table 4 means H_{0jk} was rejected. This data is also visualized in Figure 10.

The mean passage time for roundabouts in the experiment was 801 ticks, while the mean passage time for crossings was 786 ticks. However, there was no significant difference, with a t-test giving $p = 14\,\%$. H_0 was not rejected.

Comparing designs A and E, as well as B and E, becomes interesting, as they can't conclusively be ranked against each other. Pairwise t-test of the interaction effects of direction and design is shown in Table 5.

The one significant difference is between left turns in design A and E, with left turns in A taking significantly shorter time. H_{0LAE} was rejected.

Q-Q plots for each of the designs are shown in Figures 11, 12, 13, 14 and 15.

Table 2: Direction vs passage time

Direction	**Time/ticks**
Right	680
Left	901
Forward	795

Table 3: Design vs mean passage time

Design	**Time/ticks**
A	694
B	736
C	867
D	933
E	731

Table 4: Pairwise t-tests of Designs

Significant? ($p < 1\,\%$)

	A	**B**	**C**	**D**	**E**
A	-	Y	Y	Y	N
B	Y	-	Y	Y	N
C	Y	Y	-	Y	Y
D	Y	Y	Y	-	Y
E	N	N	Y	Y	-

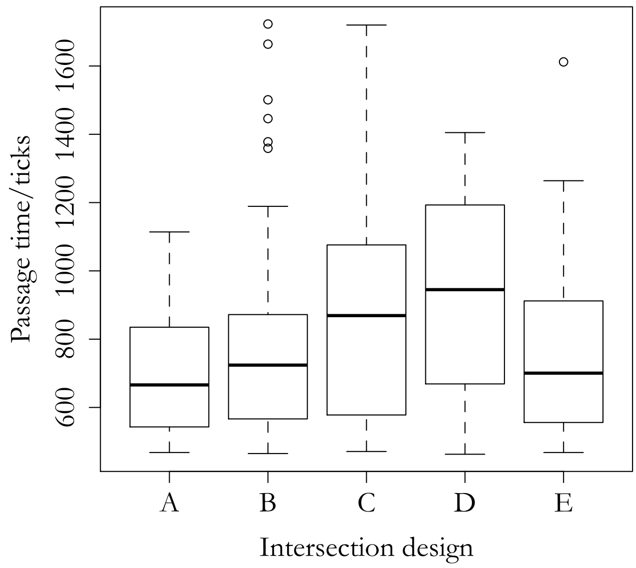

Figure 10: Passage times of different intersection designs

Table 5: Selection from pairwise t-tests of Design:Direction

	A vs E			**B vs E**		
	L	F	R	L	F	R
p	0.2 %	11.4 %	98.4 %	13.5 %	54.2 %	12.9 %

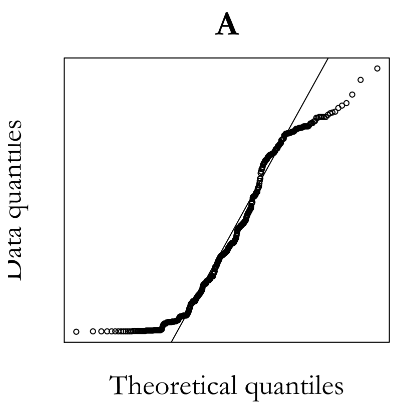

Figure 11: Normality of A

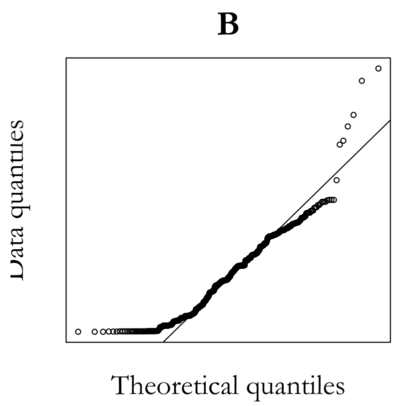

Figure 12: Normality of B

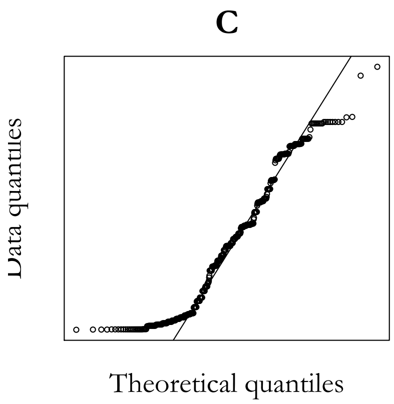

Figure 13: Normality of C

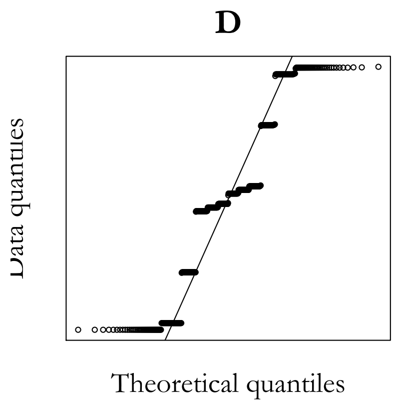

Figure 14: Normality of D

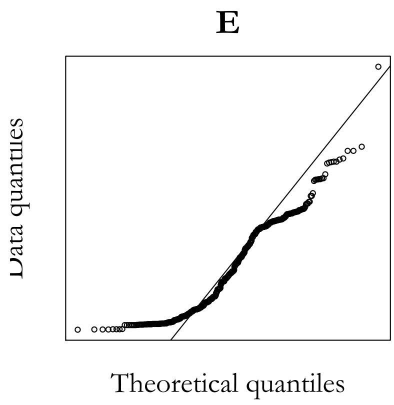

Figure 15: Normality of E

4 Discussion

As expected, left turns take significantly longer than going straight ahead, which takes significantly longer than right turns.

Oddly, north seems to have a special place in the ranking of the cardinal directions. For some reason, travelling to the north is easier than other directions, and travelling from the north takes longer. No explanation other than internal game mechanics comes to mind.

The original question, “Are roundabouts or crossings better?”, couldn’t be conclusively answered in this experiment. Even if a significant result was produced, not every possible design of both types, or a representative sample of them, were tried. What could be concluded, though, is that out of the tried designs, the best one was a crossing.

The winner of the experiment is either design A or E, with A providing stronger left turns, but the rest of the results inconclusive. B comes in at second or third place, and C and D were fourth and fifth, respectively.

As to choosing whether to use A or E, it probably comes down to other factors, like design A being cheaper in raw materials, or E being a bit more visually striking.

The tests used in this experiment are all relying heavily on normality of the data, and the less normal the data is, the less meaningful any predictions we make are. Looking at the Q-Q plots, D and E stick out as less close fits to normal distributions. This calls into question any conclusions made about these two designs here.

4.1 Outlook

Possible further experiments include

- different length trains
- more intersection designs
- further investigation of E, and where it fits in the ranking
- material cost
- further randomization of crowdedness using more trains and pseudo-random number generators

4.2 TL;DR

Use Selfdefeating’s celtic knot intersection [8] if you want to look cool while going fast, and Drizznarte’s four-way crossing [4] if you want fast left turns.

Nothing conclusive can be said on roundabouts vs. crossings.

References

[1] *Factorio official web page*, factorio.com

[2] Michal Novotny, *CircuitLogger mod*, Github.com/xmnovotny/CircuitLogger

[3] *Factorio forums*, forums.factorio.com

[4] *Drizznarte's four-way crossing*, Youtube: Factorio Workshop, Drizznarte's Rail Junctions

[5] *Mehve's roundabout*, Factorio forums: "Trying to optimize roundabouts"

[6] *Tnarg's roundabout*, Factorio forums: "Track Junctions Blueprint Strings"

[7] *Rakkfalen's spiral junction*, Youtube: Rakkfalen's Train Blueprints

[8] *Self-defeating's celtic knot intersection*, Reddit: Compact Celtic Knot Style Intersection