# A study of the suitability of synthetic data for the analysis of a health fitness dataset

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**Abstract**

Here is the abstract. **TODO[PF]: Write it.**

## 1 Introduction

A goal is for researchers to be able to safely share with each other research data pertaining to individuals.

The data must of course be adequately anonymous and must produce correct scientific analyses.

Other features as well though:

- Easy to generate the anonymous data (ideally fully automated with no anonymization expertise needed).
- Not necessary to individually approve each data release (ideally one blanket approval for the anonymization process).
- Easy to use the anonymized data for analytics (ideally, no difference between analysis using the original data and the anonymized data)

Synthetic data has been proposed as an attractive solution. A key advantage of synthetic data is that it is syntactically similar to the original data, and can therefore be directly used in a variety of data analysis tools.

This paper examines the suitability of several synthetic data methods for the purpose of data sharing.

Methodology is to take an existing analysis of an original dataset, to apply that analysis to synthetic datasets, and determine whether the same scientific conclusions are reached.

For this purpose, we use the paper [1].

Etc. etc.

**TODO[PF]: Finish first draft of intro**

## 2 Synthetic data methods

Here we describe each method.

**TODO[PF]: Finish this intro to the section.**

## 2.1 SynDiffix

**TODO[PF]: Write this section**

### 2.1.1 Overview

Describe at a very high level how the method works, why it is anonymous, and what tool is available.

### 2.1.2 Synthetic data generation

Describe the steps required to generate the synthetic version of the commute data.

### 2.1.3 Synthetic data usage

Describe the steps required to use the synthetic data in the analysis.

## 2.2 ARX

**TODO[FP]: Write this section.**

### 2.2.1 Overview

Describe at a very high level how the method works, why it is anonymous, and what tool is available.

### 2.2.2 Synthetic data generation

Describe the steps required to generate the synthetic version of the commute data.

### 2.2.3 Synthetic data usage

Describe the steps required to use the synthetic data in the analysis.

## 2.3 Synthetic Data Vault (SDV)

**TODO[PF]: Write this section.**

### 2.3.1 Overview

Describe at a very high level how the method works, why it is anonymous, and what tool is available.

### 2.3.2 Synthetic data generation

Describe the steps required to generate the synthetic version of the commute data.

### 2.3.3 Synthetic data usage

Describe the steps required to use the synthetic data in the analysis.

| | Commuting Modes | Commuting from school | | | | |
|---|---|---|---|---|---|---|
| | | Car | Public | Wheels | Walk | Total |
| **Commuting to school** | Car | **58 (8.1%)** | **54 (7.6%)** | **1 (0.1%)** | **57 (8.0%)** | **170 (23.8%)** |
| | | 58 (8.1%) | 54 (7.6%) | 0 (0.0%) | 57 (8.0%) | 169 (23.7%) |
| | | 50 (7.0%) | 72 (10.1%) | 0 (0.0%) | 60 (8.4%) | 182 (25.5%) |
| | | 20 (2.8%) | 48 (6.7%) | 15 (2.1%) | 94 (13.2%) | 177 (24.8%) |
| | Public | **10 (1.4%)** | **190 (26.6%)** | **0 (0.0%)** | **30 (4.2%)** | **230 (32.3%)** |
| | | 8 (1.1%) | 194 (27.2%) | 0 (0.0%) | 30 (4.2%) | 232 (32.5%) |
| | | 6 (0.8%) | 180 (25.2%) | 0 (0.0%) | 26 (3.6%) | 212 (29.7%) |
| | | 37 (5.2%) | 69 (9.7%) | 34 (4.8%) | 81 (11.4%) | 221 (31.0%) |
| | Wheels | **0 (0.0%)** | **0 (0.0%)** | **27 (3.8%)** | **7 (1.0%)** | **34 (4.8%)** |
| | | 0 (0.0%) | 0 (0.0%) | 29 (4.1%) | 6 (0.8%) | 35 (4.9%) |
| | | 0 (0.0%) | 0 (0.0%) | 14 (2.0%) | 17 (2.4%) | 31 (4.3%) |
| | | 20 (2.8%) | 23 (3.2%) | 13 (1.8%) | 40 (5.6%) | 96 (13.5%) |
| | Walk | **3 (0.4%)** | **1 (0.1%)** | **0 (0.0%)** | **275 (38.6%)** | **279 (39.1%)** |
| | | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 279 (39.1%) | 279 (39.1%) |
| | | 2 (0.3%) | 0 (0.0%) | 0 (0.0%) | 276 (38.7%) | 278 (39.0%) |
| | | 18 (2.5%) | 70 (9.8%) | 35 (4.9%) | 96 (13.5%) | 219 (30.7%) |
| | Total | **71 (10.0%)** | **245 (34.4%)** | **28 (3.9%)** | **369 (51.8%)** | **713 (100.0%)** |
| | | 66 (9.3%) | 248 (34.8%) | 29 (4.1%) | 372 (52.2%) | 715 (100.3%) |
| | | 58 (8.1%) | 252 (35.3%) | 14 (2.0%) | 379 (53.2%) | 703 (98.6%) |
| | | 95 (13.3%) | 210 (29.5%) | 97 (13.6%) | 311 (43.6%) | 713 (100.0%) |

Table 1: Table 1 from the paper showing the counts and percentages for the original data and the three anonymization methods. Each group of four presents the data in order of Original (bold), SynDiffix, ARX, and SDV.

# 3 Dataset

Describe the dataset we use (high level, details will be in Section 4).

Describe the rational for selecting this dataset versus possible others.

**TODO[PF]: Write this section**

# 4 Performance of the synthetic data methods

This section contains the results that would have been generated with the synthetic data had the same analysis techniques been used.

**TODO[PF]: Add text discussion of the results**

**TODO[BL]: Determine whether there are additional results that should be included here**

# 5 Analysis of the synthetic data methods

My intent for this section is that we go through the analysis from Jurak et al. [1] and for each statement decide whether the statement holds for the synthetic data.

Not sure if this should be organized by method or by statement, but I suspect the former (but with some summary table including all three methods).

| Commuting group | From home to school | | From school to home | |
|---|---|---|---|---|
| | N (%) | Distance (IQR) | N (%) | Distance (IQR) |
| Car | **170 (24%)** | **3133 (3945)** | **71 (10%)** | **3615 (3896)** |
| | 169 (24%) | 3532 (4155) | 70 (10%) | 2615 (4607) |
| | 182 (26%) | 3758 (3915) | 58 (8%) | 3910 (3800) |
| | 177 (25%) | 7602 (8467) | 95 (13%) | 3934 (7362) |
| Public | **230 (32%)** | **4782 (4296)** | **245 (34%)** | **4996 (4033)** |
| | 232 (33%) | 4676 (3960) | 245 (34%) | 5296 (3600) |
| | 212 (30%) | 4973 (4193) | 252 (35%) | 5140 (3686) |
| | 221 (31%) | 5690 (8320) | 210 (29%) | 2249 (5174) |
| Wheels | **34 (5%)** | **1366 (2211)** | **28 (4%)** | **1444 (2369)** |
| | 36 (5%) | 1097 (1254) | 30 (4%) | 1236 (2263) |
| | 31 (4%) | 1356 (1378) | 14 (2%) | 2235 (3245) |
| | 96 (13%) | 6671 (8472) | 97 (14%) | 2741 (5282) |
| Walk | **279 (39%)** | **799 (789)** | **369 (52%)** | **973 (1043)** |
| | 279 (39%) | 789 (797) | 368 (52%) | 952 (996) |
| | 278 (39%) | 805 (795) | 379 (53%) | 954 (1062) |
| | 219 (31%) | 5498 (8697) | 311 (44%) | 2374 (6068) |
| Total | **713 (100%)** | | **713 (100%)** | |
| | 716 (100%) | | 713 (100%) | |
| | 703 (99%) | | 703 (99%) | |
| | 713 (100%) | | 713 (100%) | |

Table 2: Table 2 from the original paper showing the counts and distances in meters (median and IQR) for the original data and the three anonymization methods. Each group of four presents the data in order of Original (bold), SynDiffix, ARX, and SDV. Note that the original distances median and IQR don't perfectly match those of the original Table 2 because of differences in the way median and IQR were calculated (Python versus R).

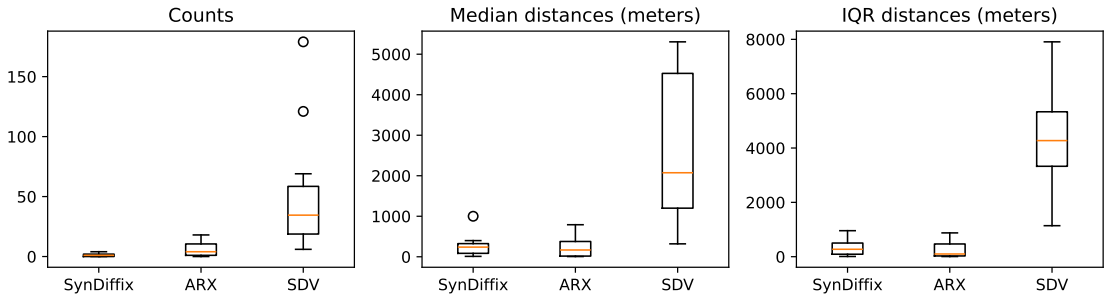



Figure 1: Absolute error of the three anonymization methods for the counts and distances in Tables 1 and 2. What we see here is that, for counts, SynDiffix is extremely accurate, but ARX is very accurate as well. SynDiffix and ARX are of equal quality for median and IQR distances. SDV is quite bad.

| Variables | Adjusted model | | | |
|---|---|---|---|---|
| | From home to school | | From school to home | |
| | Coefficient | 95% CI | Coefficient | 95% CI |
| **Constant** | **36.42*** ** | **(28.17, 44.67)** | **36.63*** ** | **(29.11, 44.15)** |
| | 32.34*** | (25.94, 38.74) | 35.49*** | (29.47, 41.5) |
| | 33.19*** | (25.82, 40.56) | 35.36*** | (28.65, 42.07) |
| | 56.08*** | (45.07, 67.09) | 49.18*** | (40.44, 57.91) |
| **Commuting group** | | | | |
| Car | **-6.49** | **(-15.92, 2.94)** | **-15.13*** | **(-26.88, -3.39)** |
| | 8.68** | (2.32, 15.04) | -7.57 | (-15.5, 0.36) |
| | -7.28 | (-15.49, 0.92) | -17.72** | (-29.65, -5.8) |
| | -9.17 | (-21.3, 2.95) | 2.4 | (-6.44, 11.24) |
| Public | **-0.08** | **(-9.06, 8.9)** | **-3.19** | **(-11.27, 4.88)** |
| | 2.93 | (-2.61, 8.48) | 2.3 | (-2.92, 7.53) |
| | 3.21 | (-4.59, 11.01) | -4.08 | (-10.99, 2.84) |
| | -6.17 | (-16.67, 4.32) | -2.57 | (-9.06, 3.92) |
| Wheels | **3.0** | **(-16.24, 22.25)** | **15.66** | **(-4.09, 35.41)** |
| | 9.95 | (-1.84, 21.74) | 6.92 | (-10.66, 24.5) |
| | 3.88 | (-11.83, 19.58) | 17.16 | (-4.9, 39.22) |
| | -8.69 | (-23.52, 6.14) | 1.48 | (-7.47, 10.44) |
| Walk (ref) | | | | |
| **Interaction Commuting group x Distance** | | | | |
| Car x Distance | **0.58** | **(-0.04, 1.2)** | **1.25** ** | **(0.34, 2.17)** |
| | -0.69** | (-1.16, -0.22) | 0.31 | (-0.37, 0.98) |
| | 0.79** | (0.24, 1.34) | 1.38** | (0.44, 2.33) |
| | 0.35 | (-0.35, 1.06) | -0.28 | (-0.94, 0.37) |
| Public x Distance | **0.06** | **(-0.49, 0.61)** | **0.33** | **(-0.21, 0.88)** |
| | -0.13 | (-0.5, 0.23) | -0.4* | (-0.77, -0.04) |
| | -0.04 | (-0.52, 0.45) | 0.37 | (-0.1, 0.84) |
| | 0.04 | (-0.48, 0.56) | 0.38 | (-0.06, 0.82) |
| Wheels x Distance | **-0.09** | **(-1.79, 1.62)** | **-1.15** | **(-2.89, 0.6)** |
| | -0.71 | (-1.66, 0.24) | -0.49 | (-1.9, 0.91) |
| | 0.08 | (-1.32, 1.48) | -1.41 | (-3.35, 0.53) |
| | 0.09 | (-0.88, 1.07) | -0.04 | (-0.75, 0.66) |
| Walk x Distance | **-0.02** | **(-0.62, 0.58)** | **0.03** | **(-0.42, 0.48)** |
| | 0.18 | (-0.15, 0.51) | -0.22 | (-0.53, 0.09) |
| | 0.17 | (-0.33, 0.68) | -0.04 | (-0.42, 0.34) |
| | -0.63 | (-1.28, 0.02) | -0.08 | (-0.44, 0.28) |

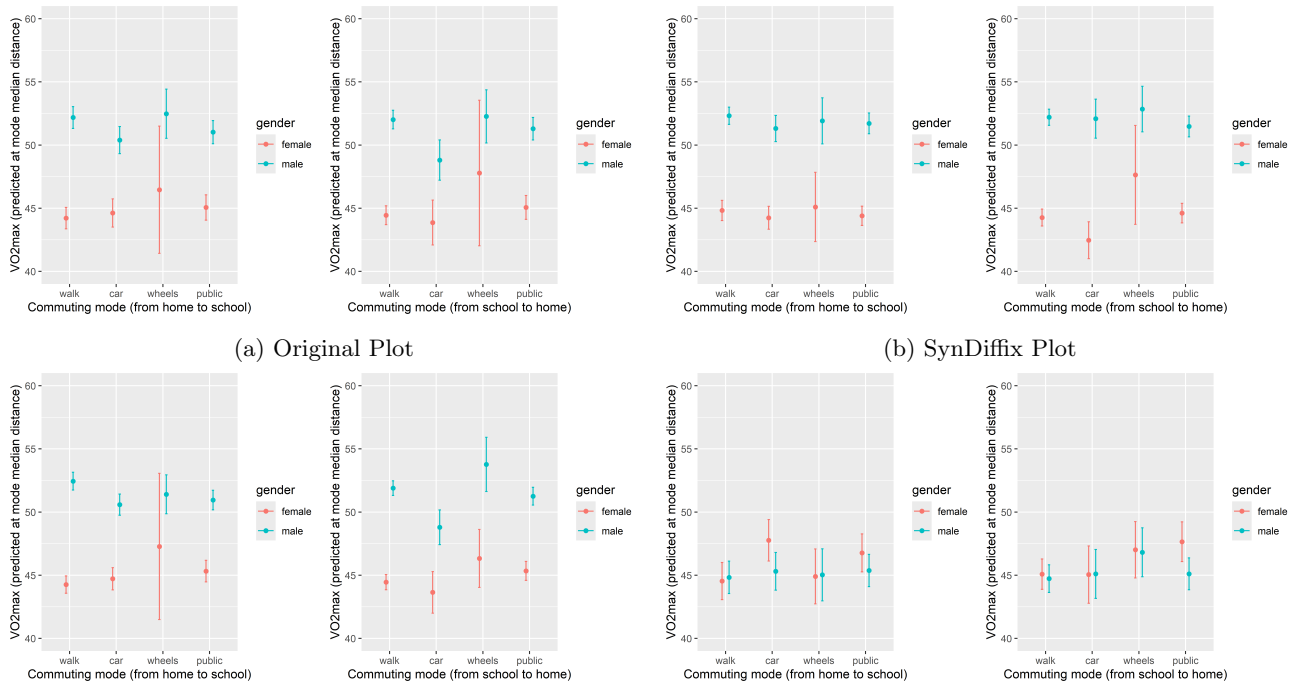
* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

Table 3: Part 1 (of 2) of the original paper's Table 3 showing the parameters (regression coefficients) of the linear model for prediction of VO2max by group and distance. Each group of four presents the data in order of Original (bold), SynDiffix, ARX, and SDV.

| **Variables** | **Adjusted model** | | | |
|---|---|---|---|---|
| | **From home to school** | | **From school to home** | |
| | **Coefficient** | **95% CI** | **Coefficient** | **95% CI** |
| **Gender** | | | | |
| Males | **7.97*** ** | **(6.75, 9.19)** | **7.58*** ** | **(6.52, 8.63)** |
| | 7.5*** | (6.45, 8.55) | 7.94*** | (7.01, 8.87) |
| | 8.19*** | (7.2, 9.18) | 7.45*** | (6.6, 8.29) |
| | 0.29 | (-1.66, 2.25) | -0.36 | (-1.99, 1.27) |
| Females (ref) | | | | |
| **Interaction Commuting group x Gender** | | | | |
| Car x Gender | **-2.2*** | **(-4.16, -0.24)** | **-2.63*** | **(-5.23, -0.03)** |
| | -0.42 | (-2.14, 1.29) | 1.68 | (-0.68, 4.04) |
| | -2.32** | (-3.86, -0.77) | -2.3* | (-4.59, -0.01) |
| | -2.75 | (-5.66, 0.16) | 0.41 | (-2.97, 3.78) |
| Public x Males | **-2.0*** | **(-3.81, -0.2)** | **-1.35** | **(-2.99, 0.3)** |
| | -0.18 | (-1.71, 1.35) | -1.08 | (-2.53, 0.37) |
| | -2.56*** | (-4.05, -1.07) | -1.53* | (-2.83, -0.22) |
| | -1.69 | (-4.46, 1.07) | -2.18 | (-4.77, 0.4) |
| Wheels x Males | **-1.95** | **(-7.49, 3.6)** | **-3.09** | **(-9.31, 3.12)** |
| | -0.68 | (-4.17, 2.81) | -2.73 | (-7.11, 1.66) |
| | -4.06 | (-10.16, 2.05) | nan | (nan, nan) |
| | -0.17 | (-3.71, 3.38) | 0.16 | (-3.25, 3.56) |
| Walk x Males (ref) | | | | |
| **Covariates** | | | | |
| MVPA | **0.08*** ** | **(0.03, 0.12)** | **0.07*** ** | **(0.03, 0.11)** |
| | 0.2*** | (0.16, 0.24) | 0.15*** | (0.11, 0.19) |
| | 0.08*** | (0.04, 0.12) | 0.07*** | (0.03, 0.12) |
| | -0.06** | (-0.11, -0.02) | -0.06** | (-0.11, -0.01) |
| Age | **0.43*** | **(0.0, 0.85)** | **0.4** | **(-0.02, 0.82)** |
| | 0.34 | (-0.03, 0.7) | 0.5** | (0.13, 0.87) |
| | 0.53** | (0.14, 0.92) | 0.55** | (0.17, 0.93) |
| | -0.11 | (-0.64, 0.42) | -0.08 | (-0.61, 0.45) |

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

Table 4: Part 2 (of 2) of the original paper's Table 3 showing the parameters (regression coefficients) of the linear model for prediction of VO2max by group and distance. Each group of four presents the data in order of Original (bold), SynDiffix, ARX, and SDV.




(a) Original Plot

(b) SynDiffix Plot

(c) ARX Plot

(d) SDV Plot

Figure 2: Comparison of the VO2max data. Here we see that ARX matches very closely with the original data. SynDiffix is quite close for female, but for reasons I don't understand yet, does somewhat bad for the car commute for males. Otherwise, though SynDiffix is pretty good. SDV is again quite bad. What will be important is whether the correct conclusions can be drown from the data in spite of the error.

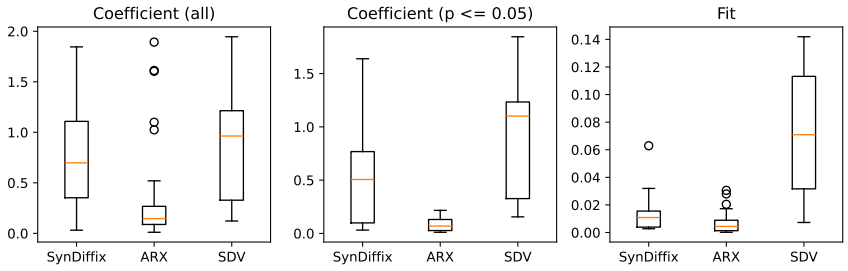



Figure 3: Normalized error for coefficients and fit for Figure 2. This reflects the quality we see in Figure 2. SynDiffix clearly has more error than ARX.

| | SDX | ARX | SDV |
|---|---|---|---|
| Of the original 12 significant p-values, method is also significat | 6 (50%) | 12 (100%) | 4 (33%) |
| Of the original 16 insignificant p-values, method is also insignificat | 12 (75%) | 13 (81%) | 16 (100%) |
| Of the original 12 significant p-values, method matches | 6 (50%) | 8 (67%) | 2 (17%) |
| Of the original 12 significant p-values, method off by 1 | 0 (0%) | 3 (25%) | 2 (17%) |
| Of the original 12 significant p-values, method off by 2 | 0 (0%) | 1 (8%) | 0 (0%) |

Table 5: Error between each method's p-values and the original p-values. P-values are significant when $p \leq 0.05$. P-values are binned as $p \leq 0.001$, $0.001 < p \leq 0.01$, and $0.01 < p \leq 0.05$. Off by 1 means that the method's bin is one off from the original data's bin (both being significant). Off by 2 means that the method's bin is two off from the original data's bin.

**TODO[BL]: The analysis for this section really has to be done by Bojan, since he is the one that understands the analysis and can reason about the synthetic data results.**

# 6 Analysis modifications

Given the limitations of the synthetic data, it might well be the case that the analysis might have been done differently mitigate those limitations. An example might be to not separate the data by commute direction.

If we identify such analysis modifications, we can give the modified results here.

**TODO[ALL]: Discuss this among ourselves.**

**TODO[PF]: Code up and run modifications**

**TODO[BL]: Analyze modifications**

## 6.1 Overall analysis

Here we give a complete analysis of all the results with respect to the main goals of being able to use the synthetic data method for data sharing.

We analyze the difficulty of building the data, data quality issues, difficulty of using the synthetic data for analysis. **TODO[BL]: This mainly needs to be done by Bojan.**

To the extent that the tools are not currently usable, we suggest improvements that can be made to the tools to make them usable. One obvious example would be tools to help the user understand how much error is in the data.

**TODO[ALL]: We can all work on this, based on the issues that Bojan identifies.**

## 6.2 Summary and future work

Blah blah blah

**TODO[ALL]: Discuss**

# References

[1] Gregor Jurak, Maroje Soric, Vedrana Sember, Sasa Djuric, Gregor Starc, Marjeta Kovac, and Bojan Leskosek. Associations of mode and distance of commuting to school with cardiorespiratory fitness in slovenian schoolchildren: a nationwide cross-sectional study. *BMC public health*, 21:1–10, 2021.