

UNIVERSITY OF TWENTE.

Traffic Operations  
201100005

Examination

30 January 2018  
13:45-16:45

| Questions                                       | Points     |
|-------------------------------------------------|------------|
| START                                           | 10         |
| PART I                                          | 40         |
| Question 1 (a: 2, b: 2, c: 2, d: 3, e: 3, f: 3) | 15         |
| Question 2 (a: 5, b: 10)                        | 15         |
| Question 3 (a: 6, b: 4)                         | 10         |
| PART II                                         | 50         |
| Question 4 (a: 5, b:5, c:2)                     | 12         |
| Question 5 (a: 4, b:4, c:2)                     | 10         |
| Question 6 (a: 5, b: 5, c: 5, d: 5, e: 8)       | 28         |
| <b>Total</b>                                    | <b>100</b> |

The exam consists of 6 questions. Points are listed in the table above. There are two parts and you are asked to use separate sheets for each part.

Good luck.

Eric van Berkum and Tom Thomas

## PART I

### Question 1 (15 points)

Rijkswaterstaat determines the locally measured individual vehicle speeds on motorways using two subsequent induction loops. Passing vehicles cause signals that are schematized as:

- $t_1$ , loop 1 is 'on'
- $t_2$ , loop 1 is 'off'
- $t_3$ , loop 2 is 'on'
- $t_4$ , loop 2 is 'off'

The length of a loop is  $y$  and the gross distance between two loops is  $x$ .

- a) Give an expression for how the individual vehicle speed  $v_i$  of vehicle  $i$  can be determined from the different time instants (2 pts).
- b) Given an expression for the mean average speed for a period (2 pts)
- c) Is this a space mean speed or a time mean speed? (2 pts)
- d) Show how an approximation of the instantaneous mean speed can be determined from these measurements. (3 pts)
- e) Suppose at some time instant the instantaneous travel time (based on speed measurements) over a stretch of road with multiple sets of dual loop detectors is presented. Under which circumstances do you think is the difference between actual realized travel time and instantaneous travel time the largest and when will both types of travel times be identical? (3 pts)
- f) Show how the length  $L_i$  of vehicle  $i$  can be determined (3 pts)

### Question 2 (15 points)

There is a plan to paint all highway bridges over the river Rhine in a new colour. It is claimed that this new colour will increase the capacity of the bridges. You are asked to 'prove' this using the product limit (Kaplan Meier) method.

- a) What measurements do you need (i.e. which flow characteristics do you measure, what type of measurement equipment do you want to use and at which locations do you want to perform the measurements)? Provide a drawing of the highway, the bridge and the locations (5 pts)
- b) Explain in detail how you are going to use the measurements in order to answer the question, i.e. describe the Kaplan Meier method (10 pts)

### Question 3 (10 points)

In a general decision model for lane changes a driver is assumed to maximize his or her utility (*incentive criterion*) subject to the condition that the action is safe (*safety criterion*).

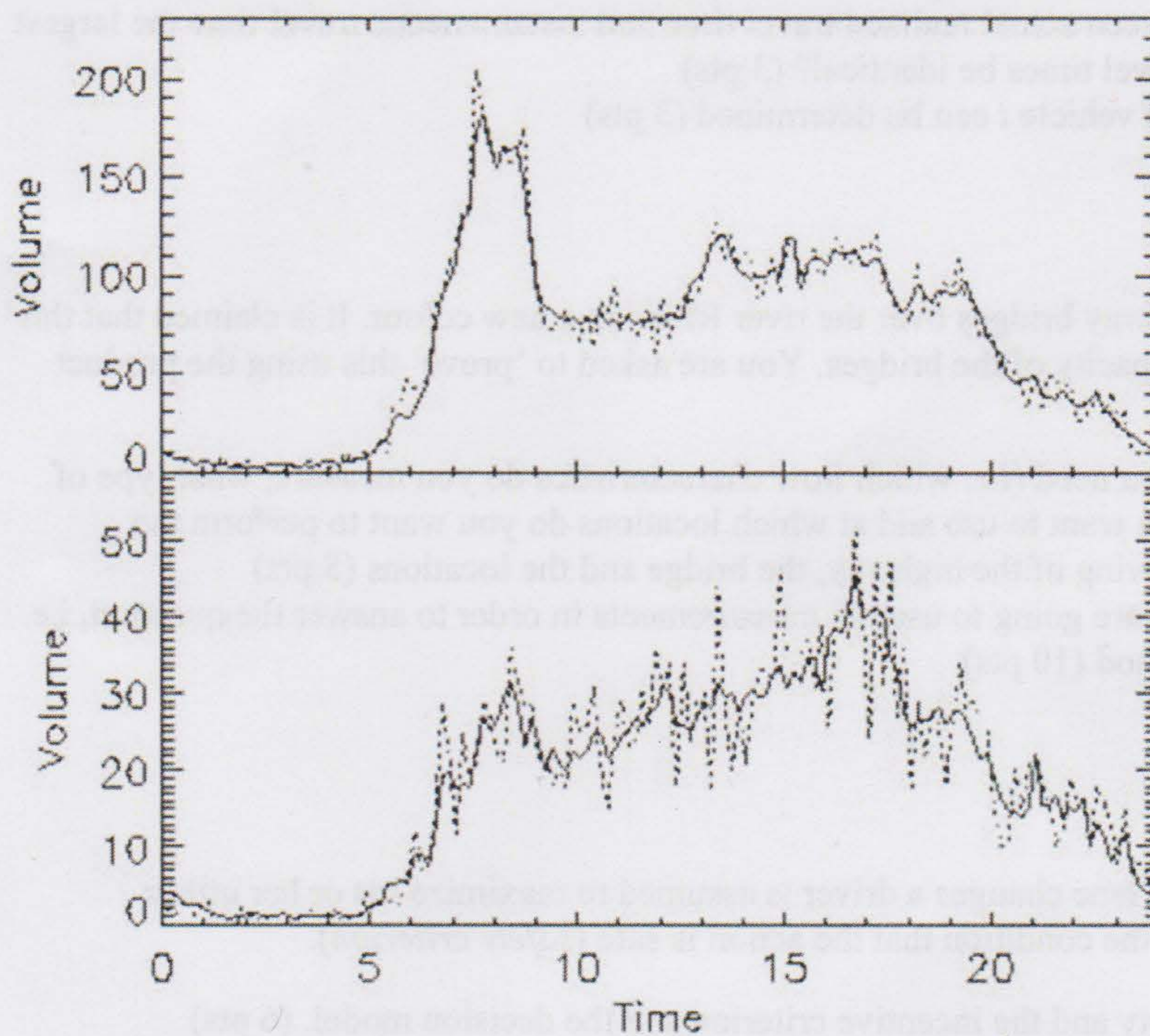
- a) Describe in detail the safety and the incentive criterion and the decision model. (6 pts)
- b) What are potential drawbacks for driving comfort when this type of model is implemented in the lateral control module of a self-driving (autonomous) vehicle (4 pts)

## Part II

Please write your derivations and answers for Part II on separate paper sheets.

4. [12 pts] The figure below shows two intensity profiles (time-series for one day). The dashed lines represent the measurements, the solid lines the predictions.

- (a) [5 pts] How do you use autocorrelation to show whether all remaining variation (w.r.t. the prediction) is random. Describe all steps using the proper formulas.
- (b) [5 pts] How can you use cross-correlation to improve the predictions. Describe all steps using the proper formulas.
- (c) [2 pts] How could the results from a & b be used to improve your prediction? Explain your answer.



5. [10 pts] Consider observed intensities with predictions. The total variance of the residuals is given by the mean square of the residuals. Suppose that the random variation can be described by a Poisson process.

- (a) [4 pts] Suppose there is no systematic variation in the residuals. Draw a figure in which the ratio between the mean square of the residuals and the average intensity (y-ordinate) is plotted versus the average intensity (x-ordinate). The average intensity lies between 5 and 50 vehicles.
- (b) [4 pts] Draw a similar figure for the case in which the systematic variation is 5 vehicles.
- (c) [2 pts] Explain the difference between both figures based on characteristics of random and systematic variation.

6. [28 pts] Consider the following BPR function to predict travel time  $TT$ , based on free-flow travel time  $TT_{ff}$ , and intensity-capacity ratio  $q/C$ :

$$TT = TT_{ff} * [1 + (q/(0.8C))^2].$$

- (a) [5 pts] Give an approximation of the random error in  $TT$ ,  $err(TT)$  due to the random error in  $TT_{ff}$ ,  $err(TT_{ff})$ , due to the random error in  $q$ ,  $err(q)$ , and due to the random error in  $C$ ,  $err(C)$ .
- (b) [5 pts] Suppose that the **relative** errors in  $TT_{ff}$ ,  $q$ , and  $C$ , i.e.,  $err(TT_{ff}) / TT_{ff}$ ,  $err(q) / q$ , and  $err(C) / C$  respectively, are the same? Which error has the largest effect on  $TT$ ? Explain your answer.
- (c) [5 pts] Suppose that the random errors in  $q$  and  $C$  are uncorrelated, estimate the total random error in  $TT$  as function of the random errors in  $q$  and  $C$ . Assume there is no random error in  $TT_{ff}$ , i.e.,  $err(TT_{ff}) = 0$
- (d) [5 pts] Bad weather will lead to higher intensities and lower capacities. Therefore we assume errors in  $q$  and  $C$  are negatively correlated. Suppose there is a perfect correlation of -1. Estimate the total random error in  $TT$  as function of the random error in  $q$ . Assume there is no random error in  $TT_{ff}$ , i.e.,  $err(TT_{ff}) = 0$ . Is the error smaller or larger than in (c)? Explain your answer.

Suppose we have the following travel time measurements during 5 days; 34.26, 41.86, 38.22, 44.61, and 32.18 minutes respectively. During the same days the measured intensities were 2417, 3560, 3211, 3387, and 2965 vehicles per hour respectively. The capacity is estimated to be 4000 vehicles per hour for each day, and the random error in the capacity is 300 vehicles per hour. The free flow travel time is 20.2 minutes with a negligibly small random error (error is 0). Suppose that there are no errors in the measurements.

- (e) [8 pts] Perform a Chi-square goodness of fit test for the BPR function. Should the BPR function be rejected? Take a significance level of 0.05.

T-distribution: Critical values of t

| Df  | Significance level |       |        |        |        |         |         |
|-----|--------------------|-------|--------|--------|--------|---------|---------|
|     | Two-tailed test:   | 0.1   | 0.05   | 0.02   | 0.01   | 0.002   | 0.001   |
|     | One-tailed test:   | 0.05  | 0.025  | 0.01   | 0.005  | 0.001   | 0.0005  |
| 1   |                    | 6.314 | 12.706 | 31.821 | 63.657 | 318.309 | 636.619 |
| 2   |                    | 2.920 | 4.303  | 6.965  | 9.925  | 22.327  | 31.599  |
| 3   |                    | 2.353 | 3.182  | 4.541  | 5.841  | 10.215  | 12.924  |
| 4   |                    | 2.132 | 2.776  | 3.747  | 4.604  | 7.173   | 8.610   |
| 5   |                    | 2.015 | 2.571  | 3.365  | 4.032  | 5.893   | 6.869   |
| 6   |                    | 1.943 | 2.447  | 3.143  | 3.707  | 5.208   | 5.959   |
| 7   |                    | 1.894 | 2.365  | 2.998  | 3.499  | 4.785   | 5.408   |
| 8   |                    | 1.860 | 2.306  | 2.896  | 3.355  | 4.501   | 5.041   |
| 9   |                    | 1.833 | 2.262  | 2.821  | 3.250  | 4.297   | 4.781   |
| 10  |                    | 1.812 | 2.228  | 2.764  | 3.169  | 4.144   | 4.587   |
| 11  |                    | 1.796 | 2.201  | 2.718  | 3.106  | 4.025   | 4.437   |
| 12  |                    | 1.782 | 2.179  | 2.681  | 3.055  | 3.930   | 4.318   |
| 13  |                    | 1.771 | 2.160  | 2.650  | 3.012  | 3.852   | 4.221   |
| 14  |                    | 1.761 | 2.145  | 2.624  | 2.977  | 3.787   | 4.140   |
| 15  |                    | 1.753 | 2.131  | 2.602  | 2.947  | 3.733   | 4.073   |
| 16  |                    | 1.746 | 2.120  | 2.583  | 2.921  | 3.686   | 4.015   |
| 17  |                    | 1.740 | 2.110  | 2.567  | 2.898  | 3.646   | 3.965   |
| 18  |                    | 1.734 | 2.101  | 2.552  | 2.878  | 3.610   | 3.922   |
| 19  |                    | 1.729 | 2.093  | 2.539  | 2.861  | 3.579   | 3.883   |
| 20  |                    | 1.725 | 2.086  | 2.528  | 2.845  | 3.552   | 3.850   |
| 21  |                    | 1.721 | 2.080  | 2.518  | 2.831  | 3.527   | 3.819   |
| 22  |                    | 1.717 | 2.074  | 2.508  | 2.819  | 3.505   | 3.792   |
| 23  |                    | 1.714 | 2.069  | 2.500  | 2.807  | 3.485   | 3.768   |
| 24  |                    | 1.711 | 2.064  | 2.492  | 2.797  | 3.467   | 3.745   |
| 25  |                    | 1.708 | 2.060  | 2.485  | 2.787  | 3.450   | 3.725   |
| 26  |                    | 1.706 | 2.056  | 2.479  | 2.779  | 3.435   | 3.707   |
| 27  |                    | 1.703 | 2.052  | 2.473  | 2.771  | 3.421   | 3.690   |
| 28  |                    | 1.701 | 2.048  | 2.467  | 2.763  | 3.408   | 3.674   |
| 29  |                    | 1.699 | 2.045  | 2.462  | 2.756  | 3.396   | 3.659   |
| 30  |                    | 1.697 | 2.042  | 2.457  | 2.750  | 3.385   | 3.646   |
| 40  |                    | 1.684 | 2.021  | 2.423  | 2.704  | 3.307   | 3.551   |
| 50  |                    | 1.676 | 2.009  | 2.403  | 2.678  | 3.261   | 3.496   |
| 60  |                    | 1.671 | 2.000  | 2.390  | 2.660  | 3.232   | 3.460   |
| 70  |                    | 1.667 | 1.994  | 2.381  | 2.648  | 3.211   | 3.435   |
| 80  |                    | 1.664 | 1.990  | 2.374  | 2.639  | 3.195   | 3.416   |
| 90  |                    | 1.662 | 1.987  | 2.368  | 2.632  | 3.183   | 3.402   |
| 100 |                    | 1.660 | 1.984  | 2.364  | 2.626  | 3.174   | 3.390   |
| 200 |                    | 1.653 | 1.972  | 2.345  | 2.601  | 3.131   | 3.340   |
| 300 |                    | 1.650 | 1.968  | 2.339  | 2.592  | 3.118   | 3.323   |
| 400 |                    | 1.649 | 1.966  | 2.336  | 2.588  | 3.111   | 3.315   |
| 500 |                    | 1.648 | 1.965  | 2.334  | 2.586  | 3.107   | 3.310   |
| 600 |                    | 1.647 | 1.964  | 2.333  | 2.584  | 3.104   | 3.307   |
| Z   |                    | 1.645 | 1.960  | 2.326  | 2.576  | 3.090   | 3.291   |

$\chi^2$  (Chi-Squared) Distribution: Critical Values of  $\chi^2$ 

| Df  | One Tailed Test: | Significance level |       |       |       |       |       |       |        |       |
|-----|------------------|--------------------|-------|-------|-------|-------|-------|-------|--------|-------|
|     |                  | 0.2                | 0.15  | 0.1   | 0.05  | 0.025 | 0.01  | 0.005 | 0.0025 | 0.001 |
| 1   |                  | 1.64               | 2.07  | 2.71  | 3.84  | 5.02  | 6.63  | 7.88  | 9.14   | 10.83 |
| 2   |                  | 3.22               | 3.79  | 4.61  | 5.99  | 7.38  | 9.21  | 10.60 | 11.98  | 13.82 |
| 3   |                  | 4.64               | 5.32  | 6.25  | 7.81  | 9.35  | 11.34 | 12.84 | 14.32  | 16.27 |
| 4   |                  | 5.59               | 6.74  | 7.78  | 9.49  | 11.14 | 13.23 | 14.86 | 16.42  | 18.47 |
| 5   |                  | 7.29               | 8.12  | 9.24  | 11.07 | 12.83 | 15.09 | 16.75 | 18.39  | 20.51 |
| 6   |                  | 8.56               | 9.45  | 10.64 | 12.53 | 14.45 | 16.81 | 18.55 | 20.25  | 22.46 |
| 7   |                  | 5.80               | 10.75 | 12.02 | 14.07 | 16.01 | 18.48 | 20.28 | 22.04  | 24.32 |
| 8   |                  | 11.03              | 12.03 | 13.36 | 15.51 | 17.53 | 20.09 | 21.95 | 23.77  | 26.12 |
| 9   |                  | 12.24              | 13.29 | 14.68 | 16.92 | 19.02 | 21.67 | 23.59 | 25.46  | 27.83 |
| 10  |                  | 13.44              | 14.53 | 15.99 | 18.31 | 20.48 | 23.21 | 25.19 | 27.11  | 29.59 |
| 11  |                  | 14.63              | 15.77 | 17.29 | 19.68 | 21.92 | 24.72 | 26.76 | 28.73  | 31.26 |
| 12  |                  | 15.81              | 16.99 | 18.55 | 21.03 | 23.34 | 26.22 | 28.30 | 30.32  | 32.91 |
| 13  |                  | 15.58              | 18.90 | 19.81 | 22.36 | 24.74 | 27.69 | 29.82 | 31.88  | 34.53 |
| 14  |                  | 18.15              | 19.4  | 21.06 | 23.68 | 26.12 | 29.14 | 31.32 | 33.43  | 36.12 |
| 15  |                  | 19.31              | 20.60 | 22.31 | 25.00 | 27.49 | 30.58 | 32.80 | 34.95  | 37.70 |
| 16  |                  | 20.47              | 21.79 | 23.54 | 26.30 | 28.85 | 32.00 | 34.27 | 36.46  | 39.25 |
| 17  |                  | 21.61              | 22.98 | 24.77 | 27.59 | 30.19 | 33.41 | 35.72 | 37.95  | 40.79 |
| 18  |                  | 22.76              | 24.16 | 25.99 | 28.87 | 31.53 | 34.81 | 37.16 | 39.42  | 42.31 |
| 19  |                  | 23.90              | 25.33 | 27.20 | 30.14 | 32.85 | 36.19 | 38.58 | 40.88  | 43.82 |
| 20  |                  | 25.04              | 26.50 | 28.41 | 31.41 | 34.17 | 37.57 | 40.00 | 42.34  | 45.31 |
| 21  |                  | 26.17              | 27.66 | 29.62 | 32.67 | 35.48 | 38.93 | 41.40 | 43.78  | 46.80 |
| 22  |                  | 27.30              | 28.82 | 30.81 | 33.92 | 36.78 | 40.29 | 42.80 | 45.20  | 48.27 |
| 23  |                  | 28.43              | 29.98 | 32.01 | 35.17 | 38.08 | 41.64 | 44.18 | 46.62  | 49.73 |
| 24  |                  | 29.55              | 31.13 | 33.20 | 36.42 | 39.36 | 42.98 | 45.56 | 48.03  | 51.18 |
| 25  |                  | 30.68              | 32.28 | 34.38 | 37.65 | 40.65 | 44.31 | 46.93 | 49.44  | 52.62 |
| 26  |                  | 31.79              | 33.43 | 35.56 | 38.89 | 41.92 | 45.64 | 48.29 | 50.83  | 54.05 |
| 27  |                  | 32.91              | 34.57 | 36.74 | 40.11 | 43.19 | 46.96 | 49.64 | 52.22  | 55.48 |
| 28  |                  | 34.03              | 35.71 | 37.92 | 41.34 | 44.46 | 48.28 | 50.99 | 53.59  | 56.89 |
| 29  |                  | 35.14              | 36.85 | 39.09 | 42.56 | 45.72 | 49.59 | 52.34 | 54.97  | 58.30 |
| 30  |                  | 36.25              | 37.99 | 40.26 | 43.77 | 46.98 | 50.89 | 53.67 | 56.33  | 59.70 |
| 40  |                  | 47.27              | 49.24 | 51.81 | 55.76 | 59.34 | 63.69 | 66.77 | 69.70  | 73.40 |
| 50  |                  | 53.16              | 60.35 | 63.17 | 67.50 | 71.42 | 76.15 | 79.49 | 82.66  | 86.66 |
| 60  |                  | 68.97              | 71.34 | 74.40 | 79.08 | 83.30 | 88.38 | 91.95 | 95.34  | 99.61 |
| 80  |                  | 90.41              | 93.11 | 96.58 | 101.9 | 106.6 | 112.3 | 116.3 | 120.1  | 124.8 |
| 100 |                  | 111.7              | 114.7 | 118.5 | 124.3 | 129.6 | 135.8 | 140.2 | 144.3  | 149.4 |