Федеральное государственное автономное образовательное

учреждение высшего образования

УНИВЕРСИТЕТ ИТМО

Дисциплина: Моделирование

**Учебно-исследовательская работа 3**

**«Исследование СМО произвольного вида»**

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**Цель работы**

Исследование свойств простейших одно- и многоканальных СМО типа G/G/K/Е с однородным потоком заявок с использованием системы имитационного моделирования GPSS при различных предположениях о параметрах структурно-функциональной организации и нагрузки в соответствии с заданной программой исследований.

**Выполнение**

Для данной работы была выбрана система 1, так как она была лучшей по критерию «минимальные потери заявок».

Система 1:

* Количество приборов 2
* Емкость накопителя первого прибора 3, второго прибора 1

Параметры нагрузки:

* (интенсивность потока)
* , с (средняя длительность обслуживания)
* Вероятности занятия приборов:

P1 = 0.4

P2 = 0.6

A diagram of a algorithm

Description automatically generated

Сравнение результатов, полученных в ходе имитационного моделирования и метода марковских процессов для СМО, выбранной в качестве наилучшей в УИР 2.

|  |  |  |  |
| --- | --- | --- | --- |
| **Характеристика** | **УИР2** | **Модель** | **Отклонение, %** |
| **Загрузка** | 0,9627 | 0.962 | 0 |
| **Длина очереди** | 3,105 | 3.102 | <1 |

Варианты организации системы

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Номер варианта | | 1 | | 2 | | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Количество приборов | | 2 | | | | | | | | | | |
| Емкости накопителей | | 3/1 | | 3/1 | | 7/7 | 3/1 | 3/1 | 7/7 | 3/1 | 3/1 | 7/7 |
| Интервалы между заявками входящего потока | Ср. Значение | 125,7 | | 125,7 | | 125,7 | 125,7 | 125,7 | 125,7 | 123,1 | 123,1 | 123,1 |
| Вид потока | Простейший | | | | | Трасса | | | Аппроксимация | | |
| Длительность обслуживания заявок | Ср. Значение | 250 | 500 | | 250 | | 250 | 500 | 250 | 250 | 500 | 250 |
| Коэф-т вариации | 1 | 1 | | 1 | | 1,025 | 1,025 | 1,025 | 1,124 | 1,124 | 1,124 |

**Результаты имитационного моделирования**

Желтым в таблице отмечен момент переходного процесса. После этого режим системы можно считать остановившимся, так как вероятность потери, длина очереди и загрузка практически не изменяются со временем.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Исх. Данные (вариант 1)** | | **K** | **E** | **поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 3/1 | прост | 125.7 | 250 | 1 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 0 | 0.0 | 0 | 1.042 | 0.682 | 15.966 | === | 36.096 | 22.373 | 140.126 |
| 20 | 2 | 10.0 | 0 | 1.410 | 0.795 | 233.805 | 1364.393 | 311.305 | 136.435 | 58.354 |
| 50 | 9 | 18.0 | 80.0 | 0.829 | 0.573 | 115.972 | 50.398 | 231.736 | 64.234 | 55.387 |
| 100 | 28 | 28.0 | 55.556 | 1.699 | 0.740 | 282.045 | 143.201 | 427.819 | 83.853 | 29.73 |
| 200 | 58 | 29.0 | 3.571 | 1.200 | 0.721 | 197.785 | 29.875 | 292.911 | 40.595 | 20.525 |
| 500 | 147 | 29.4 | 1.379 | 1.206 | 0.711 | 223.492 | 12.997 | 339.209 | 29.733 | 13.304 |
| 1000 | 268 | 26.8 | 8.844 | 1.269 | 0.718 | 220.889 | 1.165 | 337.524 | 20.92 | 9.471 |
| 2000 | 576 | 28.8 | 7.463 | 1.126 | 0.688 | 206.294 | 6.607 | 313.023 | 13.719 | 6.65 |
| 5000 | 1294 | 25.88 | 10.139 | 1.178 | 0.696 | 203.471 | 1.368 | 313.186 | 8.681 | 4.266 |
| 10000 | 2925 | 29.25 | 13.022 | 1.288 | 0.712 | 226.295 | 11.217 | 339.259 | 6.649 | 2.938 |
| 20000 | 5666 | 28.33 | 3.145 | 1.240 | 0.712 | 216.873 | 4.164 | 321.796 | 4.46 | 2.056 |
| 50000 | 14190 | 28.38 | 0.176 | 1.236 | 0.711 | 216.193 | 0.314 | 317.944 | 2.787 | 1.289 |
| 100000 | 28331 | 28.331 | 0.173 | 1.224 | 0.708 | 215.419 | 0.358 | 323.754 | 2.007 | 0.932 |
| 150000 | 42482 | 28.321 | 0.034 | 1.243 | 0.710 | 218.585 | 1.47 | 327.243 | 1.656 | 0.758 |
| 200000 | 57090 | 28.545 | 0.79 | 1.247 | 0.711 | 219.315 | 0.334 | 326.103 | 1.429 | 0.652 |
| 300000 | 85037 | 28.346 | 0.698 | 1.242 | 0.711 | 217.859 | 0.664 | 325.229 | 1.164 | 0.534 |
| 350000 | 99529 | 28.437 | 0.322 | 1.249 | 0.713 | 219.399 | 0.707 | 325.177 | 1.077 | 0.491 |
| 400000 | 114020 | 28.505 | 0.24 | 1.245 | 0.712 | 218.667 | 0.334 | 325.238 | 1.008 | 0.461 |
| 500000 | 142136 | 28.427 | 0.273 | 1.247 | 0.713 | 219.047 | 0.174 | 325.939 | 0.903 | 0.412 |
| 1000000 | 284479 | 28.448 | 0.073 | 1.244 | 0.711 | 218.478 | 0.26 | 326.175 | 0.639 | 0.293 |

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| **Исх. Данные (вариант 2)** | | **K** | **E** | **поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 3/1 | прост | 125.7 | 500 | 1 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 4 | 40.0 | === | 1.537 | 0.894 | 124.643 | === | 141.872 | 87.933 | 70.548 |
| 20 | 9 | 45.0 | 12.5 | 1.507 | 0.775 | 354.824 | 184.672 | 715.381 | 313.53 | 88.362 |
| 50 | 21 | 42.0 | 6.667 | 2.148 | 0.865 | 427.143 | 20.382 | 493.405 | 136.765 | 32.019 |
| 100 | 57 | 57.0 | 35.714 | 2.565 | 0.915 | 716.660 | 67.78 | 722.141 | 141.54 | 19.75 |
| 200 | 110 | 55.0 | 3.509 | 2.050 | 0.863 | 526.104 | 26.589 | 777.259 | 107.723 | 20.476 |
| 500 | 262 | 52.4 | 4.727 | 2.585 | 0.940 | 697.633 | 32.604 | 710.582 | 62.285 | 8.928 |
| 1000 | 558 | 55.8 | 6.489 | 2.657 | 0.920 | 769.949 | 10.366 | 899.382 | 55.744 | 7.24 |
| 2000 | 1071 | 53.55 | 4.032 | 2.512 | 0.901 | 702.107 | 8.811 | 823.587 | 36.095 | 5.141 |
| 5000 | 2610 | 52.2 | 2.521 | 2.463 | 0.899 | 660.469 | 5.93 | 780.886 | 21.645 | 3.277 |
| 10000 | 5372 | 53.72 | 2.912 | 2.499 | 0.906 | 670.162 | 1.468 | 780.864 | 15.305 | 2.284 |
| 20000 | 10854 | 54.27 | 1.024 | 2.540 | 0.917 | 695.834 | 3.831 | 782.004 | 10.838 | 1.558 |
| 50000 | 26943 | 53.886 | 0.708 | 2.541 | 0.914 | 689.984 | 0.841 | 773.516 | 6.78 | 0.983 |
| 100000 | 53793 | 53.793 | 0.173 | 2.523 | 0.911 | 688.575 | 0.204 | 782.221 | 4.848 | 0.704 |
| 150000 | 80820 | 53.88 | 0.162 | 2.530 | 0.911 | 691.565 | 0.434 | 794.900 | 4.023 | 0.582 |
| 200000 | 108325 | 54.163 | 0.524 | 2.548 | 0.912 | 698.729 | 1.036 | 789.592 | 3.461 | 0.495 |
| 300000 | 162230 | 54.077 | 0.158 | 2.555 | 0.914 | 699.261 | 0.076 | 792.026 | 2.834 | 0.405 |
| 350000 | 189251 | 54.072 | 0.009 | 2.544 | 0.913 | 696.218 | 0.435 | 786.519 | 2.606 | 0.374 |
| 400000 | 216538 | 54.134 | 0.116 | 2.545 | 0.913 | 696.847 | 0.09 | 788.290 | 2.443 | 0.351 |
| 500000 | 270496 | 54.099 | 0.065 | 2.547 | 0.913 | 697.426 | 0.083 | 787.455 | 2.183 | 0.313 |
| 1000000 | 541774 | 54.177 | 0.145 | 2.544 | 0.913 | 697.754 | 0.047 | 788.289 | 1.545 | 0.221 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Исх. Данные (вариант 3)** | | **K** | **E** | **поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 7/7 | прост | 125.7 | 250 | 1 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 0 | 0.0 | 0 | 1.042 | 0.682 | 15.966 | === | 36.096 | 22.373 | 140.126 |
| 20 | 0 | 0.0 | 0 | 1.725 | 0.907 | 255.191 | 1498.34 | 289.954 | 127.078 | 49.797 |
| 50 | 0 | 0.0 | 0 | 3.243 | 0.778 | 360.565 | 41.292 | 329.619 | 91.366 | 25.34 |
| 100 | 4 | 4.0 | 0 | 6.148 | 0.846 | 765.447 | 112.291 | 782.599 | 153.389 | 20.039 |
| 200 | 21 | 10.5 | 162.5 | 6.252 | 0.864 | 892.709 | 16.626 | 645.384 | 89.446 | 10.02 |
| 500 | 79 | 15.8 | 50.476 | 6.463 | 0.858 | 984.622 | 10.296 | 824.671 | 72.286 | 7.341 |
| 1000 | 142 | 14.2 | 10.127 | 6.091 | 0.838 | 913.004 | 7.274 | 763.710 | 47.335 | 5.185 |
| 2000 | 247 | 12.35 | 13.028 | 5.126 | 0.820 | 760.518 | 16.702 | 732.333 | 32.096 | 4.22 |
| 5000 | 573 | 11.46 | 7.206 | 5.492 | 0.841 | 795.129 | 4.551 | 741.397 | 20.55 | 2.585 |
| 10000 | 1496 | 14.96 | 30.541 | 6.153 | 0.860 | 899.599 | 13.139 | 777.588 | 15.241 | 1.694 |
| 20000 | 2765 | 13.825 | 7.587 | 5.887 | 0.847 | 856.487 | 4.792 | 744.243 | 10.315 | 1.204 |
| 50000 | 6823 | 13.646 | 1.295 | 6.048 | 0.859 | 877.202 | 2.419 | 753.899 | 6.608 | 0.753 |
| 100000 | 13512 | 13.512 | 0.982 | 5.942 | 0.853 | 866.252 | 1.248 | 757.065 | 4.692 | 0.542 |
| 150000 | 20515 | 13.677 | 1.219 | 5.960 | 0.857 | 870.626 | 0.505 | 751.891 | 3.805 | 0.437 |
| 200000 | 27305 | 13.652 | 0.177 | 5.978 | 0.858 | 870.288 | 0.039 | 752.346 | 3.297 | 0.379 |
| 300000 | 40555 | 13.518 | 0.983 | 6.004 | 0.861 | 872.553 | 0.26 | 753.335 | 2.696 | 0.309 |
| 350000 | 48336 | 13.81 | 2.16 | 6.035 | 0.858 | 880.229 | 0.88 | 758.254 | 2.512 | 0.285 |
| 400000 | 55604 | 13.901 | 0.657 | 5.995 | 0.858 | 874.653 | 0.633 | 756.018 | 2.343 | 0.268 |
| 500000 | 68178 | 13.636 | 1.909 | 6.007 | 0.860 | 874.130 | 0.06 | 755.508 | 2.094 | 0.24 |
| 1000000 | 136740 | 13.674 | 0.282 | 5.984 | 0.859 | 871.133 | 0.343 | 752.900 | 1.476 | 0.169 |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Исх. Данные (вариант 4)** | | **K** | **E** | **Поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 3/1 | трасс | 125.7 | 250 | 1.025 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 0 | 0.0 | 0 | 0.295 | 0.434 | 31.793 | === | 72.816 | 45.132 | 141.955 |
| 20 | 8 | 40.0 | 0 | 0.451 | 0.441 | 137.088 | 331.189 | 334.288 | 146.508 | 106.872 |
| 50 | 6 | 12.0 | 70.0 | 0.562 | 0.515 | 69.069 | 49.617 | 159.017 | 44.077 | 63.816 |
| 100 | 21 | 21.0 | 75.0 | 1.214 | 0.676 | 232.101 | 236.042 | 391.504 | 76.735 | 33.061 |
| 200 | 54 | 27.0 | 28.571 | 1.105 | 0.659 | 205.183 | 11.598 | 334.769 | 46.397 | 22.612 |
| 500 | 161 | 32.2 | 19.259 | 1.230 | 0.688 | 230.313 | 12.248 | 340.658 | 29.86 | 12.965 |
| 1000 | 291 | 29.1 | 9.627 | 1.139 | 0.690 | 206.115 | 10.507 | 321.211 | 19.909 | 9.659 |
| 2000 | 603 | 30.15 | 3.608 | 1.211 | 0.698 | 219.565 | 6.525 | 332.631 | 14.578 | 6.64 |
| 5000 | 1423 | 28.46 | 5.605 | 1.091 | 0.675 | 192.372 | 12.385 | 303.928 | 8.424 | 4.379 |
| 10000 | 3068 | 30.68 | 7.8 | 1.177 | 0.689 | 213.938 | 11.211 | 326.096 | 6.391 | 2.988 |
| 20000 | 5991 | 29.955 | 2.363 | 1.188 | 0.695 | 213.422 | 0.241 | 318.561 | 4.415 | 2.069 |
| 50000 | 14846 | 29.692 | 0.878 | 1.229 | 0.695 | 219.877 | 3.025 | 331.206 | 2.903 | 1.32 |
| 100000 | 30050 | 30.05 | 1.206 | 1.216 | 0.692 | 218.595 | 0.583 | 326.623 | 2.024 | 0.926 |
| 150000 | 44901 | 29.934 | 0.386 | 1.225 | 0.697 | 219.736 | 0.522 | 331.046 | 1.675 | 0.762 |
| 200000 | 60125 | 30.062 | 0.429 | 1.221 | 0.695 | 219.549 | 0.085 | 328.702 | 1.441 | 0.656 |
| 300000 | 89570 | 29.857 | 0.685 | 1.221 | 0.696 | 218.778 | 0.351 | 327.390 | 1.172 | 0.535 |
| 350000 | 105247 | 30.071 | 0.716 | 1.224 | 0.697 | 220.054 | 0.583 | 327.344 | 1.084 | 0.493 |
| 400000 | 120282 | 30.07 | 0.0 | 1.222 | 0.696 | 219.634 | 0.191 | 328.131 | 1.017 | 0.463 |
| 500000 | 150316 | 30.063 | 0.024 | 1.230 | 0.696 | 221.108 | 0.671 | 329.443 | 0.913 | 0.413 |
| 1000000 | 300284 | 30.028 | 0.116 | 1.222 | 0.696 | 219.563 | 0.699 | 329.217 | 0.645 | 0.294 |

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| **Исх. Данные (вариант 5)** | | **K** | **E** | **Поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 3/1 | трасс | 125.7 | 500 | 1.025 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 1 | 10.0 | === | 0.700 | 0.584 | 88.355 | === | 160.620 | 99.553 | 112.674 |
| 20 | 10 | 50.0 | 400.0 | 0.793 | 0.731 | 283.842 | 221.252 | 705.803 | 309.332 | 108.98 |
| 50 | 14 | 28.0 | 44.0 | 1.224 | 0.720 | 237.167 | 16.444 | 315.385 | 87.42 | 36.86 |
| 100 | 52 | 52.0 | 85.714 | 2.323 | 0.849 | 719.341 | 203.306 | 782.338 | 153.338 | 21.316 |
| 200 | 96 | 48.0 | 7.692 | 2.031 | 0.874 | 523.008 | 27.293 | 672.254 | 93.17 | 17.814 |
| 500 | 274 | 54.8 | 14.167 | 2.581 | 0.885 | 741.518 | 41.779 | 826.096 | 72.411 | 9.765 |
| 1000 | 572 | 57.2 | 4.38 | 2.634 | 0.910 | 786.436 | 6.058 | 873.685 | 54.152 | 6.886 |
| 2000 | 1094 | 54.7 | 4.371 | 2.410 | 0.898 | 672.977 | 14.427 | 796.360 | 34.902 | 5.186 |
| 5000 | 2679 | 53.58 | 2.048 | 2.362 | 0.889 | 640.471 | 4.83 | 747.581 | 20.722 | 3.235 |
| 10000 | 5378 | 53.78 | 0.373 | 2.395 | 0.893 | 652.515 | 1.88 | 751.415 | 14.728 | 2.257 |
| 20000 | 11036 | 55.18 | 2.603 | 2.422 | 0.896 | 679.657 | 4.16 | 782.806 | 10.849 | 1.596 |
| 50000 | 27260 | 54.52 | 1.196 | 2.442 | 0.897 | 675.289 | 0.643 | 781.784 | 6.853 | 1.015 |
| 100000 | 54540 | 54.54 | 0.037 | 2.441 | 0.898 | 675.241 | 0.007 | 784.981 | 4.865 | 0.721 |
| 150000 | 81933 | 54.622 | 0.15 | 2.451 | 0.899 | 679.025 | 0.56 | 786.556 | 3.981 | 0.586 |
| 200000 | 109479 | 54.739 | 0.215 | 2.464 | 0.902 | 684.414 | 0.794 | 789.391 | 3.46 | 0.505 |
| 300000 | 164112 | 54.704 | 0.065 | 2.472 | 0.902 | 686.083 | 0.244 | 788.269 | 2.821 | 0.411 |
| 350000 | 191253 | 54.644 | 0.11 | 2.450 | 0.901 | 679.225 | 1.0 | 782.238 | 2.592 | 0.382 |
| 400000 | 218810 | 54.703 | 0.108 | 2.448 | 0.900 | 679.564 | 0.05 | 780.779 | 2.42 | 0.356 |
| 500000 | 273786 | 54.757 | 0.1 | 2.459 | 0.900 | 683.294 | 0.549 | 785.876 | 2.178 | 0.319 |
| 1000000 | 547306 | 54.731 | 0.049 | 2.466 | 0.902 | 684.842 | 0.227 | 783.996 | 1.537 | 0.224 |

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| **Исх. Данные (вариант 6)** | | **K** | **E** | **Поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 7/7 | трасс | 125.7 | 250 | 1.025 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 0 | 0.0 | 0 | 0.295 | 0.434 | 31.793 | === | 72.816 | 45.132 | 141.955 |
| 20 | 0 | 0.0 | 0 | 4.303 | 0.617 | 732.686 | 2204.551 | 705.839 | 309.348 | 42.221 |
| 50 | 0 | 0.0 | 0 | 2.138 | 0.622 | 312.920 | 57.291 | 448.756 | 124.389 | 39.751 |
| 100 | 2 | 2.0 | 0 | 3.553 | 0.705 | 550.129 | 75.805 | 705.633 | 138.304 | 25.14 |
| 200 | 22 | 11.0 | 450.0 | 4.781 | 0.799 | 703.749 | 27.924 | 621.161 | 86.089 | 12.233 |
| 500 | 85 | 17.0 | 54.545 | 6.181 | 0.842 | 955.313 | 35.746 | 790.655 | 69.304 | 7.255 |
| 1000 | 130 | 13.0 | 23.529 | 5.880 | 0.849 | 869.486 | 8.984 | 766.331 | 47.498 | 5.463 |
| 2000 | 297 | 14.85 | 14.231 | 5.573 | 0.816 | 830.524 | 4.481 | 767.542 | 33.639 | 4.05 |
| 5000 | 694 | 13.88 | 6.532 | 5.738 | 0.831 | 840.574 | 1.21 | 729.017 | 20.207 | 2.404 |
| 10000 | 1569 | 15.69 | 13.04 | 6.063 | 0.842 | 906.063 | 7.791 | 775.937 | 15.208 | 1.679 |
| 20000 | 2988 | 14.94 | 4.78 | 5.649 | 0.835 | 835.652 | 7.771 | 730.906 | 10.13 | 1.212 |
| 50000 | 7586 | 15.172 | 1.553 | 5.762 | 0.840 | 854.264 | 2.227 | 761.648 | 6.676 | 0.782 |
| 100000 | 15415 | 15.415 | 1.602 | 5.763 | 0.836 | 856.754 | 0.291 | 768.242 | 4.762 | 0.556 |
| 150000 | 23249 | 15.499 | 0.547 | 5.854 | 0.842 | 870.998 | 1.663 | 763.648 | 3.865 | 0.444 |
| 200000 | 30495 | 15.248 | 1.625 | 5.774 | 0.841 | 856.562 | 1.657 | 757.965 | 3.322 | 0.388 |
| 300000 | 45895 | 15.298 | 0.333 | 5.812 | 0.842 | 862.704 | 0.717 | 756.734 | 2.708 | 0.314 |
| 350000 | 54219 | 15.491 | 1.26 | 5.815 | 0.841 | 865.039 | 0.271 | 763.273 | 2.529 | 0.292 |
| 400000 | 62051 | 15.513 | 0.139 | 5.832 | 0.841 | 867.798 | 0.319 | 760.524 | 2.357 | 0.272 |
| 500000 | 77187 | 15.437 | 0.486 | 5.814 | 0.842 | 864.426 | 0.389 | 762.739 | 2.114 | 0.245 |
| 1000000 | 152939 | 15.294 | 0.93 | 5.815 | 0.842 | 863.077 | 0.156 | 757.808 | 1.485 | 0.172 |

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| **Исх. Данные (вариант 7)** | | **K** | **E** | **Поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 3/1 | аппр | 123.1 | 250 | 1.124 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 1 | 10.0 | === | 0.228 | 0.395 | 15.863 | === | 52.613 | 32.61 | 205.572 |
| 20 | 7 | 35.0 | 250.0 | 0.855 | 0.621 | 169.314 | 967.352 | 344.783 | 151.108 | 89.247 |
| 50 | 14 | 28.0 | 20.0 | 0.701 | 0.589 | 71.847 | 57.566 | 128.974 | 35.75 | 49.758 |
| 100 | 32 | 32.0 | 14.286 | 1.800 | 0.780 | 310.401 | 332.031 | 388.935 | 76.231 | 24.559 |
| 200 | 55 | 27.5 | 14.062 | 1.274 | 0.746 | 206.300 | 33.538 | 269.305 | 37.324 | 18.092 |
| 500 | 161 | 32.2 | 17.091 | 1.409 | 0.749 | 250.789 | 21.565 | 351.254 | 30.789 | 12.277 |
| 1000 | 291 | 29.1 | 9.627 | 1.306 | 0.718 | 225.866 | 9.938 | 307.923 | 19.085 | 8.45 |
| 2000 | 603 | 30.15 | 3.608 | 1.342 | 0.722 | 234.611 | 3.872 | 342.076 | 14.992 | 6.39 |
| 5000 | 1393 | 27.86 | 7.595 | 1.174 | 0.699 | 200.062 | 14.726 | 302.529 | 8.386 | 4.192 |
| 10000 | 2906 | 29.06 | 4.307 | 1.296 | 0.721 | 224.845 | 12.388 | 328.625 | 6.441 | 2.865 |
| 20000 | 5845 | 29.225 | 0.568 | 1.266 | 0.719 | 220.049 | 2.133 | 323.850 | 4.488 | 2.04 |
| 50000 | 14605 | 29.21 | 0.051 | 1.278 | 0.716 | 222.160 | 0.959 | 323.747 | 2.838 | 1.277 |
| 100000 | 29117 | 29.117 | 0.318 | 1.286 | 0.717 | 223.263 | 0.496 | 330.181 | 2.046 | 0.917 |
| 150000 | 43995 | 29.33 | 0.732 | 1.283 | 0.718 | 223.400 | 0.061 | 328.914 | 1.665 | 0.745 |
| 200000 | 58249 | 29.124 | 0.701 | 1.291 | 0.720 | 224.226 | 0.37 | 329.399 | 1.444 | 0.644 |
| 300000 | 87321 | 29.107 | 0.06 | 1.292 | 0.718 | 224.322 | 0.043 | 328.391 | 1.175 | 0.524 |
| 350000 | 102496 | 29.285 | 0.61 | 1.286 | 0.719 | 223.843 | 0.214 | 327.579 | 1.085 | 0.485 |
| 400000 | 117175 | 29.294 | 0.031 | 1.284 | 0.718 | 223.593 | 0.112 | 328.275 | 1.017 | 0.455 |
| 500000 | 146362 | 29.272 | 0.073 | 1.294 | 0.720 | 225.157 | 0.699 | 329.136 | 0.912 | 0.405 |
| 1000000 | 292008 | 29.201 | 0.245 | 1.289 | 0.719 | 224.130 | 0.456 | 328.863 | 0.645 | 0.288 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Исх. Данные (вариант 8)** | | **K** | **E** | **Поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 3/1 | аппр | 123.1 | 500 | 1.124 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 1 | 10.0 | === | 1.069 | 0.673 | 67.467 | === | 146.167 | 90.595 | 134.281 |
| 20 | 15 | 75.0 | 650.0 | 1.452 | 0.716 | 412.505 | 511.417 | 949.570 | 416.167 | 100.888 |
| 50 | 23 | 46.0 | 38.667 | 2.247 | 0.885 | 429.092 | 4.021 | 432.786 | 119.962 | 27.957 |
| 100 | 57 | 57.0 | 23.913 | 2.953 | 0.894 | 756.320 | 76.261 | 875.709 | 171.639 | 22.694 |
| 200 | 110 | 55.0 | 3.509 | 2.275 | 0.891 | 566.724 | 25.068 | 828.483 | 114.822 | 20.261 |
| 500 | 285 | 57.0 | 3.636 | 2.622 | 0.913 | 722.201 | 27.434 | 823.549 | 72.187 | 9.995 |
| 1000 | 584 | 58.4 | 2.456 | 2.724 | 0.922 | 794.834 | 10.057 | 887.338 | 54.998 | 6.919 |
| 2000 | 1113 | 55.65 | 4.709 | 2.556 | 0.906 | 694.009 | 12.685 | 787.204 | 34.501 | 4.971 |
| 5000 | 2674 | 53.48 | 3.899 | 2.511 | 0.911 | 661.490 | 4.686 | 755.392 | 20.938 | 3.165 |
| 10000 | 5409 | 54.09 | 1.141 | 2.558 | 0.910 | 685.782 | 3.672 | 777.754 | 15.244 | 2.223 |
| 20000 | 11016 | 55.08 | 1.83 | 2.573 | 0.917 | 704.705 | 2.759 | 801.314 | 11.106 | 1.576 |
| 50000 | 27300 | 54.6 | 0.871 | 2.592 | 0.916 | 702.603 | 0.298 | 783.389 | 6.867 | 0.977 |
| 100000 | 54740 | 54.74 | 0.256 | 2.574 | 0.914 | 700.102 | 0.356 | 787.927 | 4.884 | 0.698 |
| 150000 | 82190 | 54.793 | 0.097 | 2.572 | 0.914 | 700.222 | 0.017 | 793.467 | 4.015 | 0.573 |
| 200000 | 110042 | 55.021 | 0.416 | 2.583 | 0.915 | 706.774 | 0.936 | 795.594 | 3.487 | 0.493 |
| 300000 | 164841 | 54.947 | 0.134 | 2.575 | 0.916 | 703.637 | 0.444 | 789.856 | 2.826 | 0.402 |
| 350000 | 192136 | 54.896 | 0.093 | 2.579 | 0.916 | 703.916 | 0.04 | 794.222 | 2.631 | 0.374 |
| 400000 | 219515 | 54.879 | 0.031 | 2.578 | 0.915 | 703.224 | 0.098 | 785.368 | 2.434 | 0.346 |
| 500000 | 274590 | 54.918 | 0.072 | 2.583 | 0.916 | 705.410 | 0.311 | 792.834 | 2.198 | 0.312 |
| 1000000 | 549852 | 54.985 | 0.122 | 2.585 | 0.916 | 706.794 | 0.196 | 790.754 | 1.55 | 0.219 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Исх. Данные (вариант 9)** | | **K** | **E** | **Поток** | **a** | **b** | **KB** |  |  |  |
| 2 | 7/7 | аппр | 123.1 | 250 | 1.124 |  |  |  |
| **Заявок** | **Потери** | **Вер-ть потери** | **П (%)** | **Длина очер.** | **Загрузка** | **Ср.вр. ож.** | **О (%)** | **Ско вр. Ож.** | **Дов. инт.** | **Д (%)** |
| 10 | 0 | 0.0 | 0 | 0.274 | 0.410 | 15.863 | === | 52.613 | 32.61 | 205.572 |
| 20 | 2 | 10.0 | 0 | 4.867 | 0.750 | 563.511 | 3452.361 | 443.992 | 194.588 | 34.531 |
| 50 | 1 | 2.0 | 80.0 | 3.620 | 0.715 | 337.042 | 40.189 | 387.744 | 107.477 | 31.888 |
| 100 | 12 | 12.0 | 500.0 | 6.159 | 0.872 | 801.903 | 137.924 | 716.295 | 140.394 | 17.508 |
| 200 | 34 | 17.0 | 41.667 | 5.828 | 0.844 | 825.675 | 2.964 | 726.940 | 100.749 | 12.202 |
| 500 | 89 | 17.8 | 4.706 | 6.628 | 0.884 | 979.377 | 18.615 | 818.870 | 71.777 | 7.329 |
| 1000 | 160 | 16.0 | 10.112 | 6.009 | 0.867 | 872.702 | 10.892 | 787.372 | 48.802 | 5.592 |
| 2000 | 260 | 13.0 | 18.75 | 5.905 | 0.859 | 832.809 | 4.571 | 745.717 | 32.682 | 3.924 |
| 5000 | 658 | 13.16 | 1.231 | 6.129 | 0.859 | 867.024 | 4.108 | 729.118 | 20.21 | 2.331 |
| 10000 | 1464 | 14.64 | 11.246 | 6.416 | 0.871 | 924.863 | 6.671 | 770.446 | 15.101 | 1.633 |
| 20000 | 2818 | 14.09 | 3.757 | 6.073 | 0.861 | 869.940 | 5.939 | 738.825 | 10.24 | 1.177 |
| 50000 | 6794 | 13.588 | 3.563 | 6.193 | 0.875 | 881.996 | 1.386 | 747.229 | 6.55 | 0.743 |
| 100000 | 14127 | 14.127 | 3.967 | 6.196 | 0.868 | 888.105 | 0.693 | 763.507 | 4.732 | 0.533 |
| 150000 | 21117 | 14.078 | 0.347 | 6.246 | 0.873 | 894.882 | 0.763 | 753.400 | 3.813 | 0.426 |
| 200000 | 28097 | 14.049 | 0.21 | 6.216 | 0.872 | 890.243 | 0.518 | 750.200 | 3.288 | 0.369 |
| 300000 | 42575 | 14.192 | 1.019 | 6.195 | 0.872 | 888.703 | 0.173 | 756.440 | 2.707 | 0.305 |
| 350000 | 49723 | 14.207 | 0.105 | 6.208 | 0.872 | 890.672 | 0.222 | 758.205 | 2.512 | 0.282 |
| 400000 | 56997 | 14.249 | 0.3 | 6.245 | 0.872 | 896.528 | 0.657 | 754.899 | 2.339 | 0.261 |
| 500000 | 70962 | 14.192 | 0.399 | 6.221 | 0.872 | 892.405 | 0.46 | 756.939 | 2.098 | 0.235 |
| 1000000 | 141031 | 14.103 | 0.629 | 6.203 | 0.872 | 889.007 | 0.381 | 754.221 | 1.478 | 0.166 |

**Сравнительный анализ результатов моделирования**

В каждом из трех видов входного потока заявок при увеличении средней длительности обслуживания в два раза наблюдается заметный рост вероятности потерь, обусловленный тем, что заявки будут чаще теряться, ведь приборы будут чаще заняты. При увеличении же емкостей накопителей вероятность потери значительно снижается, ведь в прибор попадает больше заявок, чем могло попасть раньше.

Анализируя длину очереди при различных конфигурациях системы мы приходим к выводу что она прямо пропорциональна и средней длительности обслуживания, и емкости накопителей.

При увеличении средней длительности обслуживания с 250 до 500 загрузка системы увеличивается в среднем с 70 процентов до 90. При увеличении емкости накопителей до 7 на каждом приборе загрузка увеличивается в среднем до 85 процентов.

Средее время ожидания также прямо пропорционально обоим из параметров: средней длительности обслуживания и емкости накопителей.

**Гистограммы плотности распределения времени ожидания в очереди**

1. Вариант 1 (экспоненциальное распределение)\

A screenshot of a computer

Description automatically generated

1. Вариант 2 (трасса)

A graph with numbers and a number of bars

Description automatically generated with medium confidence

1. Вариант 3 (аппроксимация)