

CW

binara

2025-02-25

```
library(queueing)
library(simmer)

## Warning: package 'simmer' was built under R version 4.3.3

library(ggplot2)

## Warning: package 'ggplot2' was built under R version 4.3.3

library(dplyr)

##
## Attaching package: 'dplyr'

## The following object is masked from 'package:simmer':
##
##   select

## The following objects are masked from 'package:stats':
##
##   filter, lag

## The following objects are masked from 'package:base':
##
##   intersect, setdiff, setequal, union

cust_arrival<-10/60
service_time<-1/5

set.seed(2021)
bank_queue<-simmer("Bank Queue")

customer <- trajectory("customer") %>%
  seize("server",1) %>%
  timeout(function() rexp(1,service_time))%>%
  release("server")

bank_queue %>%
  add_resource("server",2)%>%
  add_generator("customer",customer,function() rexp(1,cust_arrival))

## simmer environment: Bank Queue | now: 0 | next: 0
## { Monitor: in memory }
## { Resource: server | monitored: TRUE | server status: 0(2) | queue status:
```

```

0(Inf) }
## { Source: customer | monitored: 1 | n_generated: 0 }

bank_queue %>%
  run(until = 480)

## simmer environment: Bank Queue | now: 480 | next: 480.038182231747
## { Monitor: in memory }
## { Resource: server | monitored: TRUE | server status: 1(2) | queue status:
0(Inf) }
## { Source: customer | monitored: 1 | n_generated: 81 }

bank_2 <- get_mon_arrivals(bank_queue)
bank_2_resource <- get_mon_resources(bank_queue)

```

```
get_mon_arrivals(bank_queue)
```

##		name	start_time	end_time	activity_time	finished	replication
## 1	customer0	7.110369	8.473606	1.36323769	TRUE	1	
## 2	customer1	14.431114	15.835503	1.40438915	TRUE	1	
## 3	customer2	16.847266	20.001481	3.15421536	TRUE	1	
## 4	customer3	21.406463	22.080996	0.67453370	TRUE	1	
## 5	customer4	21.519863	25.017025	3.49716146	TRUE	1	
## 6	customer6	25.426425	26.356924	0.93049879	TRUE	1	
## 7	customer5	25.360497	27.251741	1.89124411	TRUE	1	
## 8	customer7	34.444067	37.495600	3.05153224	TRUE	1	
## 9	customer9	35.446861	38.095113	0.59951294	TRUE	1	
## 10	customer8	35.310549	38.436959	3.12641009	TRUE	1	
## 11	customer10	36.074055	39.572715	1.47760224	TRUE	1	
## 12	customer11	45.390226	48.328800	2.93857429	TRUE	1	
## 13	customer13	54.277598	55.852146	1.57454801	TRUE	1	
## 14	customer14	54.781145	56.164158	0.31201165	TRUE	1	
## 15	customer12	54.208210	57.441502	3.23329183	TRUE	1	
## 16	customer15	68.244029	77.672292	9.42826308	TRUE	1	
## 17	customer16	75.082833	77.717165	2.63433204	TRUE	1	
## 18	customer17	80.826634	81.063537	0.23690277	TRUE	1	
## 19	customer18	105.134722	111.521797	6.38707491	TRUE	1	
## 20	customer19	118.697737	129.363878	10.66614109	TRUE	1	
## 21	customer21	127.554544	129.616455	0.25257679	TRUE	1	
## 22	customer20	122.849782	139.374811	16.52502976	TRUE	1	
## 23	customer22	144.602776	146.018882	1.41610579	TRUE	1	
## 24	customer24	156.882679	157.693852	0.81117326	TRUE	1	
## 25	customer23	149.963714	159.743963	9.78024933	TRUE	1	
## 26	customer25	161.932126	164.487326	2.55520065	TRUE	1	
## 27	customer26	164.521545	169.155985	4.63443929	TRUE	1	
## 28	customer28	171.883357	177.471726	5.58836907	TRUE	1	
## 29	customer29	172.859793	177.884952	0.41322602	TRUE	1	
## 30	customer30	177.719330	179.539109	1.65415623	TRUE	1	
## 31	customer27	166.864925	190.364560	23.49963436	TRUE	1	
## 32	customer31	189.683602	193.359618	3.67601597	TRUE	1	
## 33	customer33	195.930728	195.994730	0.06400169	TRUE	1	

## 34	customer32	191.575961	202.259965	10.68400421	TRUE	1
## 35	customer34	215.440753	221.167695	5.72694226	TRUE	1
## 36	customer36	225.584321	227.724227	2.13990601	TRUE	1
## 37	customer35	219.821391	228.802862	8.98147126	TRUE	1
## 38	customer37	234.578541	234.758365	0.17982439	TRUE	1
## 39	customer38	235.162096	240.904493	5.74239725	TRUE	1
## 40	customer39	235.767263	242.310128	6.54286472	TRUE	1
## 41	customer40	236.104646	244.495409	3.59091560	TRUE	1
## 42	customer42	246.818435	250.187949	3.36951368	TRUE	1
## 43	customer43	249.093863	256.011015	5.82306667	TRUE	1
## 44	customer41	245.589406	257.536940	11.94753404	TRUE	1
## 45	customer44	260.077175	263.742637	3.66546221	TRUE	1
## 46	customer46	265.617049	268.263627	2.64657883	TRUE	1
## 47	customer45	264.798757	286.736110	21.93735264	TRUE	1
## 48	customer47	270.222940	291.015181	20.79224150	TRUE	1
## 49	customer49	289.967216	292.645635	1.63045352	TRUE	1
## 50	customer48	272.662722	300.305223	13.56911271	TRUE	1
## 51	customer50	292.193753	300.909706	8.26407191	TRUE	1
## 52	customer51	295.688244	302.438618	2.13339513	TRUE	1
## 53	customer53	301.315255	303.337181	0.89856360	TRUE	1
## 54	customer52	301.243520	306.638548	5.39502841	TRUE	1
## 55	customer54	305.926149	306.984866	1.05871699	TRUE	1
## 56	customer55	317.495241	321.389338	3.89409751	TRUE	1
## 57	customer56	339.537205	340.461405	0.92419997	TRUE	1
## 58	customer57	341.622414	348.195953	6.57353993	TRUE	1
## 59	customer58	347.298765	351.289202	3.99043643	TRUE	1
## 60	customer59	360.287957	370.472940	10.18498348	TRUE	1
## 61	customer61	369.437625	372.030960	1.55801946	TRUE	1
## 62	customer60	364.461228	375.254648	10.79342046	TRUE	1
## 63	customer63	375.256027	376.053675	0.79764859	TRUE	1
## 64	customer62	372.112905	385.828439	13.71553373	TRUE	1
## 65	customer65	391.093414	392.904459	1.81104515	TRUE	1
## 66	customer64	387.667627	406.888917	19.22129040	TRUE	1
## 67	customer66	406.401058	407.591876	1.19081784	TRUE	1
## 68	customer68	425.067340	431.083914	6.01657361	TRUE	1
## 69	customer67	423.578556	438.161312	14.58275583	TRUE	1
## 70	customer69	427.313550	446.600765	15.51685125	TRUE	1
## 71	customer71	443.254575	450.050949	3.45018442	TRUE	1
## 72	customer72	444.816619	451.092089	1.04113926	TRUE	1
## 73	customer73	444.959107	451.668710	0.57662138	TRUE	1
## 74	customer74	445.100414	453.727962	2.05925164	TRUE	1
## 75	customer75	453.288018	454.508341	0.78037948	TRUE	1
## 76	customer70	441.466668	458.990724	17.52405639	TRUE	1
## 77	customer77	460.192415	462.151201	1.95878669	TRUE	1
## 78	customer78	468.081429	473.396340	5.31491162	TRUE	1
## 79	customer76	455.588869	474.052528	18.46365939	TRUE	1

`get_mon_resources(bank_queue)`

##	resource	time	server	queue	capacity	queue_size	system	limit
## 1	server	7.110369	1	0	2	Inf	1	Inf
## 2	server	8.473606	0	0	2	Inf	0	Inf
## 3	server	14.431114	1	0	2	Inf	1	Inf
## 4	server	15.835503	0	0	2	Inf	0	Inf
## 5	server	16.847266	1	0	2	Inf	1	Inf
## 6	server	20.001481	0	0	2	Inf	0	Inf
## 7	server	21.406463	1	0	2	Inf	1	Inf
## 8	server	21.519863	2	0	2	Inf	2	Inf
## 9	server	22.080996	1	0	2	Inf	1	Inf
## 10	server	25.017025	0	0	2	Inf	0	Inf
## 11	server	25.360497	1	0	2	Inf	1	Inf
## 12	server	25.426425	2	0	2	Inf	2	Inf
## 13	server	26.356924	1	0	2	Inf	1	Inf
## 14	server	27.251741	0	0	2	Inf	0	Inf
## 15	server	34.444067	1	0	2	Inf	1	Inf
## 16	server	35.310549	2	0	2	Inf	2	Inf
## 17	server	35.446861	2	1	2	Inf	3	Inf
## 18	server	36.074055	2	2	2	Inf	4	Inf
## 19	server	37.495600	2	1	2	Inf	3	Inf
## 20	server	38.095113	2	0	2	Inf	2	Inf
## 21	server	38.436959	1	0	2	Inf	1	Inf
## 22	server	39.572715	0	0	2	Inf	0	Inf
## 23	server	45.390226	1	0	2	Inf	1	Inf
## 24	server	48.328800	0	0	2	Inf	0	Inf
## 25	server	54.208210	1	0	2	Inf	1	Inf
## 26	server	54.277598	2	0	2	Inf	2	Inf
## 27	server	54.781145	2	1	2	Inf	3	Inf
## 28	server	55.852146	2	0	2	Inf	2	Inf
## 29	server	56.164158	1	0	2	Inf	1	Inf
## 30	server	57.441502	0	0	2	Inf	0	Inf
## 31	server	68.244029	1	0	2	Inf	1	Inf
## 32	server	75.082833	2	0	2	Inf	2	Inf
## 33	server	77.672292	1	0	2	Inf	1	Inf
## 34	server	77.717165	0	0	2	Inf	0	Inf
## 35	server	80.826634	1	0	2	Inf	1	Inf
## 36	server	81.063537	0	0	2	Inf	0	Inf
## 37	server	105.134722	1	0	2	Inf	1	Inf
## 38	server	111.521797	0	0	2	Inf	0	Inf
## 39	server	118.697737	1	0	2	Inf	1	Inf
## 40	server	122.849782	2	0	2	Inf	2	Inf
## 41	server	127.554544	2	1	2	Inf	3	Inf
## 42	server	129.363878	2	0	2	Inf	2	Inf
## 43	server	129.616455	1	0	2	Inf	1	Inf
## 44	server	139.374811	0	0	2	Inf	0	Inf
## 45	server	144.602776	1	0	2	Inf	1	Inf
## 46	server	146.018882	0	0	2	Inf	0	Inf
## 47	server	149.963714	1	0	2	Inf	1	Inf
## 48	server	156.882679	2	0	2	Inf	2	Inf
## 49	server	157.693852	1	0	2	Inf	1	Inf

## 50	server	159.743963	0	0	2	Inf	0	Inf
## 51	server	161.932126	1	0	2	Inf	1	Inf
## 52	server	164.487326	0	0	2	Inf	0	Inf
## 53	server	164.521545	1	0	2	Inf	1	Inf
## 54	server	166.864925	2	0	2	Inf	2	Inf
## 55	server	169.155985	1	0	2	Inf	1	Inf
## 56	server	171.883357	2	0	2	Inf	2	Inf
## 57	server	172.859793	2	1	2	Inf	3	Inf
## 58	server	177.471726	2	0	2	Inf	2	Inf
## 59	server	177.719330	2	1	2	Inf	3	Inf
## 60	server	177.884952	2	0	2	Inf	2	Inf
## 61	server	179.539109	1	0	2	Inf	1	Inf
## 62	server	189.683602	2	0	2	Inf	2	Inf
## 63	server	190.364560	1	0	2	Inf	1	Inf
## 64	server	191.575961	2	0	2	Inf	2	Inf
## 65	server	193.359618	1	0	2	Inf	1	Inf
## 66	server	195.930728	2	0	2	Inf	2	Inf
## 67	server	195.994730	1	0	2	Inf	1	Inf
## 68	server	202.259965	0	0	2	Inf	0	Inf
## 69	server	215.440753	1	0	2	Inf	1	Inf
## 70	server	219.821391	2	0	2	Inf	2	Inf
## 71	server	221.167695	1	0	2	Inf	1	Inf
## 72	server	225.584321	2	0	2	Inf	2	Inf
## 73	server	227.724227	1	0	2	Inf	1	Inf
## 74	server	228.802862	0	0	2	Inf	0	Inf
## 75	server	234.578541	1	0	2	Inf	1	Inf
## 76	server	234.758365	0	0	2	Inf	0	Inf
## 77	server	235.162096	1	0	2	Inf	1	Inf
## 78	server	235.767263	2	0	2	Inf	2	Inf
## 79	server	236.104646	2	1	2	Inf	3	Inf
## 80	server	240.904493	2	0	2	Inf	2	Inf
## 81	server	242.310128	1	0	2	Inf	1	Inf
## 82	server	244.495409	0	0	2	Inf	0	Inf
## 83	server	245.589406	1	0	2	Inf	1	Inf
## 84	server	246.818435	2	0	2	Inf	2	Inf
## 85	server	249.093863	2	1	2	Inf	3	Inf
## 86	server	250.187949	2	0	2	Inf	2	Inf
## 87	server	256.011015	1	0	2	Inf	1	Inf
## 88	server	257.536940	0	0	2	Inf	0	Inf
## 89	server	260.077175	1	0	2	Inf	1	Inf
## 90	server	263.742637	0	0	2	Inf	0	Inf
## 91	server	264.798757	1	0	2	Inf	1	Inf
## 92	server	265.617049	2	0	2	Inf	2	Inf
## 93	server	268.263627	1	0	2	Inf	1	Inf
## 94	server	270.222940	2	0	2	Inf	2	Inf
## 95	server	272.662722	2	1	2	Inf	3	Inf
## 96	server	286.736110	2	0	2	Inf	2	Inf
## 97	server	289.967216	2	1	2	Inf	3	Inf
## 98	server	291.015181	2	0	2	Inf	2	Inf
## 99	server	292.193753	2	1	2	Inf	3	Inf

## 100	server	292.645635	2	0	2	Inf	2	Inf
## 101	server	295.688244	2	1	2	Inf	3	Inf
## 102	server	300.305223	2	0	2	Inf	2	Inf
## 103	server	300.909706	1	0	2	Inf	1	Inf
## 104	server	301.243520	2	0	2	Inf	2	Inf
## 105	server	301.315255	2	1	2	Inf	3	Inf
## 106	server	302.438618	2	0	2	Inf	2	Inf
## 107	server	303.337181	1	0	2	Inf	1	Inf
## 108	server	305.926149	2	0	2	Inf	2	Inf
## 109	server	306.638548	1	0	2	Inf	1	Inf
## 110	server	306.984866	0	0	2	Inf	0	Inf
## 111	server	317.495241	1	0	2	Inf	1	Inf
## 112	server	321.389338	0	0	2	Inf	0	Inf
## 113	server	339.537205	1	0	2	Inf	1	Inf
## 114	server	340.461405	0	0	2	Inf	0	Inf
## 115	server	341.622414	1	0	2	Inf	1	Inf
## 116	server	347.298765	2	0	2	Inf	2	Inf
## 117	server	348.195953	1	0	2	Inf	1	Inf
## 118	server	351.289202	0	0	2	Inf	0	Inf
## 119	server	360.287957	1	0	2	Inf	1	Inf
## 120	server	364.461228	2	0	2	Inf	2	Inf
## 121	server	369.437625	2	1	2	Inf	3	Inf
## 122	server	370.472940	2	0	2	Inf	2	Inf
## 123	server	372.030960	1	0	2	Inf	1	Inf
## 124	server	372.112905	2	0	2	Inf	2	Inf
## 125	server	375.254648	1	0	2	Inf	1	Inf
## 126	server	375.256027	2	0	2	Inf	2	Inf
## 127	server	376.053675	1	0	2	Inf	1	Inf
## 128	server	385.828439	0	0	2	Inf	0	Inf
## 129	server	387.667627	1	0	2	Inf	1	Inf
## 130	server	391.093414	2	0	2	Inf	2	Inf
## 131	server	392.904459	1	0	2	Inf	1	Inf
## 132	server	406.401058	2	0	2	Inf	2	Inf
## 133	server	406.888917	1	0	2	Inf	1	Inf
## 134	server	407.591876	0	0	2	Inf	0	Inf
## 135	server	423.578556	1	0	2	Inf	1	Inf
## 136	server	425.067340	2	0	2	Inf	2	Inf
## 137	server	427.313550	2	1	2	Inf	3	Inf
## 138	server	431.083914	2	0	2	Inf	2	Inf
## 139	server	438.161312	1	0	2	Inf	1	Inf
## 140	server	441.466668	2	0	2	Inf	2	Inf
## 141	server	443.254575	2	1	2	Inf	3	Inf
## 142	server	444.816619	2	2	2	Inf	4	Inf
## 143	server	444.959107	2	3	2	Inf	5	Inf
## 144	server	445.100414	2	4	2	Inf	6	Inf
## 145	server	446.600765	2	3	2	Inf	5	Inf
## 146	server	450.050949	2	2	2	Inf	4	Inf
## 147	server	451.092089	2	1	2	Inf	3	Inf
## 148	server	451.668710	2	0	2	Inf	2	Inf
## 149	server	453.288018	2	1	2	Inf	3	Inf

## 150	server	453.727962	2	0	2	Inf	2	Inf
## 151	server	454.508341	1	0	2	Inf	1	Inf
## 152	server	455.588869	2	0	2	Inf	2	Inf
## 153	server	458.990724	1	0	2	Inf	1	Inf
## 154	server	460.192415	2	0	2	Inf	2	Inf
## 155	server	462.151201	1	0	2	Inf	1	Inf
## 156	server	468.081429	2	0	2	Inf	2	Inf
## 157	server	473.396340	1	0	2	Inf	1	Inf
## 158	server	474.052528	0	0	2	Inf	0	Inf
## 159	server	474.170313	1	0	2	Inf	1	Inf
##	replication							
## 1		1						
## 2		1						
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## 120	1
## 121	1
## 122	1
## 123	1
## 124	1
## 125	1
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## 127	1
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## 130	1
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## 135	1
## 136	1
## 137	1
## 138	1
## 139	1

```
## 140      1
## 141      1
## 142      1
## 143      1
## 144      1
## 145      1
## 146      1
## 147      1
## 148      1
## 149      1
## 150      1
## 151      1
## 152      1
## 153      1
## 154      1
## 155      1
## 156      1
## 157      1
## 158      1
## 159      1
```

```
bank_2$waiting_time <-(bank_2$end_time -bank_2$start_time -
bank_2$activity_time)
bank_2
```

##	name	start_time	end_time	activity_time	finished	replication
## 1	customer0	7.110369	8.473606	1.36323769	TRUE	1
## 2	customer1	14.431114	15.835503	1.40438915	TRUE	1
## 3	customer2	16.847266	20.001481	3.15421536	TRUE	1
## 4	customer3	21.406463	22.080996	0.67453370	TRUE	1
## 5	customer4	21.519863	25.017025	3.49716146	TRUE	1
## 6	customer6	25.426425	26.356924	0.93049879	TRUE	1
## 7	customer5	25.360497	27.251741	1.89124411	TRUE	1
## 8	customer7	34.444067	37.495600	3.05153224	TRUE	1
## 9	customer9	35.446861	38.095113	0.59951294	TRUE	1
## 10	customer8	35.310549	38.436959	3.12641009	TRUE	1
## 11	customer10	36.074055	39.572715	1.47760224	TRUE	1
## 12	customer11	45.390226	48.328800	2.93857429	TRUE	1
## 13	customer13	54.277598	55.852146	1.57454801	TRUE	1
## 14	customer14	54.781145	56.164158	0.31201165	TRUE	1
## 15	customer12	54.208210	57.441502	3.23329183	TRUE	1
## 16	customer15	68.244029	77.672292	9.42826308	TRUE	1
## 17	customer16	75.082833	77.717165	2.63433204	TRUE	1
## 18	customer17	80.826634	81.063537	0.23690277	TRUE	1
## 19	customer18	105.134722	111.521797	6.38707491	TRUE	1
## 20	customer19	118.697737	129.363878	10.66614109	TRUE	1
## 21	customer21	127.554544	129.616455	0.25257679	TRUE	1
## 22	customer20	122.849782	139.374811	16.52502976	TRUE	1
## 23	customer22	144.602776	146.018882	1.41610579	TRUE	1
## 24	customer24	156.882679	157.693852	0.81117326	TRUE	1

##	25	customer23	149.963714	159.743963	9.78024933	TRUE	1
##	26	customer25	161.932126	164.487326	2.55520065	TRUE	1
##	27	customer26	164.521545	169.155985	4.63443929	TRUE	1
##	28	customer28	171.883357	177.471726	5.58836907	TRUE	1
##	29	customer29	172.859793	177.884952	0.41322602	TRUE	1
##	30	customer30	177.719330	179.539109	1.65415623	TRUE	1
##	31	customer27	166.864925	190.364560	23.49963436	TRUE	1
##	32	customer31	189.683602	193.359618	3.67601597	TRUE	1
##	33	customer33	195.930728	195.994730	0.06400169	TRUE	1
##	34	customer32	191.575961	202.259965	10.68400421	TRUE	1
##	35	customer34	215.440753	221.167695	5.72694226	TRUE	1
##	36	customer36	225.584321	227.724227	2.13990601	TRUE	1
##	37	customer35	219.821391	228.802862	8.98147126	TRUE	1
##	38	customer37	234.578541	234.758365	0.17982439	TRUE	1
##	39	customer38	235.162096	240.904493	5.74239725	TRUE	1
##	40	customer39	235.767263	242.310128	6.54286472	TRUE	1
##	41	customer40	236.104646	244.495409	3.59091560	TRUE	1
##	42	customer42	246.818435	250.187949	3.36951368	TRUE	1
##	43	customer43	249.093863	256.011015	5.82306667	TRUE	1
##	44	customer41	245.589406	257.536940	11.94753404	TRUE	1
##	45	customer44	260.077175	263.742637	3.66546221	TRUE	1
##	46	customer46	265.617049	268.263627	2.64657883	TRUE	1
##	47	customer45	264.798757	286.736110	21.93735264	TRUE	1
##	48	customer47	270.222940	291.015181	20.79224150	TRUE	1
##	49	customer49	289.967216	292.645635	1.63045352	TRUE	1
##	50	customer48	272.662722	300.305223	13.56911271	TRUE	1
##	51	customer50	292.193753	300.909706	8.26407191	TRUE	1
##	52	customer51	295.688244	302.438618	2.13339513	TRUE	1
##	53	customer53	301.315255	303.337181	0.89856360	TRUE	1
##	54	customer52	301.243520	306.638548	5.39502841	TRUE	1
##	55	customer54	305.926149	306.984866	1.05871699	TRUE	1
##	56	customer55	317.495241	321.389338	3.89409751	TRUE	1
##	57	customer56	339.537205	340.461405	0.92419997	TRUE	1
##	58	customer57	341.622414	348.195953	6.57353993	TRUE	1
##	59	customer58	347.298765	351.289202	3.99043643	TRUE	1
##	60	customer59	360.287957	370.472940	10.18498348	TRUE	1
##	61	customer61	369.437625	372.030960	1.55801946	TRUE	1
##	62	customer60	364.461228	375.254648	10.79342046	TRUE	1
##	63	customer63	375.256027	376.053675	0.79764859	TRUE	1
##	64	customer62	372.112905	385.828439	13.71553373	TRUE	1
##	65	customer65	391.093414	392.904459	1.81104515	TRUE	1
##	66	customer64	387.667627	406.888917	19.22129040	TRUE	1
##	67	customer66	406.401058	407.591876	1.19081784	TRUE	1
##	68	customer68	425.067340	431.083914	6.01657361	TRUE	1
##	69	customer67	423.578556	438.161312	14.58275583	TRUE	1
##	70	customer69	427.313550	446.600765	15.51685125	TRUE	1
##	71	customer71	443.254575	450.050949	3.45018442	TRUE	1
##	72	customer72	444.816619	451.092089	1.04113926	TRUE	1
##	73	customer73	444.959107	451.668710	0.57662138	TRUE	1
##	74	customer74	445.100414	453.727962	2.05925164	TRUE	1

## 75	customer75	453.288018	454.508341	0.78037948	TRUE	1
## 76	customer70	441.466668	458.990724	17.52405639	TRUE	1
## 77	customer77	460.192415	462.151201	1.95878669	TRUE	1
## 78	customer78	468.081429	473.396340	5.31491162	TRUE	1
## 79	customer76	455.588869	474.052528	18.46365939	TRUE	1
##	waiting_time					
## 1		0.000000e+00				
## 2		0.000000e+00				
## 3		0.000000e+00				
## 4		0.000000e+00				
## 5		-1.332268e-15				
## 6		-1.221245e-15				
## 7		1.332268e-15				
## 8		-3.552714e-15				
## 9		2.048739e+00				
## 10		3.552714e-15				
## 11		2.021057e+00				
## 12		0.000000e+00				
## 13		0.000000e+00				
## 14		1.071002e+00				
## 15		0.000000e+00				
## 16		5.329071e-15				
## 17		0.000000e+00				
## 18		0.000000e+00				
## 19		-5.329071e-15				
## 20		-1.776357e-15				
## 21		1.809334e+00				
## 22		1.065814e-14				
## 23		-1.243450e-14				
## 24		6.106227e-15				
## 25		8.881784e-15				
## 26		0.000000e+00				
## 27		9.769963e-15				
## 28		8.881784e-15				
## 29		4.611933e+00				
## 30		1.656225e-01				
## 31		0.000000e+00				
## 32		-3.108624e-15				
## 33		0.000000e+00				
## 34		0.000000e+00				
## 35		1.776357e-15				
## 36		0.000000e+00				
## 37		-8.881784e-15				
## 38		-2.359224e-15				
## 39		8.881784e-15				
## 40		-1.332268e-14				
## 41		4.799847e+00				
## 42		0.000000e+00				
## 43		1.094085e+00				
## 44		2.842171e-14				

```
## 45 9.325873e-15
## 46 0.000000e+00
## 47 2.486900e-14
## 48 -1.421085e-14
## 49 1.047965e+00
## 50 1.407339e+01
## 51 4.518816e-01
## 52 4.616979e+00
## 53 1.123363e+00
## 54 8.881784e-15
## 55 -1.110223e-14
## 56 2.664535e-15
## 57 -2.642331e-14
## 58 8.881784e-15
## 59 9.325873e-15
## 60 1.776357e-14
## 61 1.035315e+00
## 62 -2.842171e-14
## 63 0.000000e+00
## 64 -2.842171e-14
## 65 0.000000e+00
## 66 -2.131628e-14
## 67 1.421085e-14
## 68 8.881784e-15
## 69 -1.953993e-14
## 70 3.770363e+00
## 71 3.346190e+00
## 72 5.234330e+00
## 73 6.132982e+00
## 74 6.568296e+00
## 75 4.399436e-01
## 76 -1.065814e-14
## 77 0.000000e+00
## 78 8.881784e-15
## 79 -1.065814e-14
```

```
set.seed(2021)
```

```
new_bank_queue<-simmer("Bank Queue")
```

```
customer<-trajectory("customer")%>%
```

```
  seize("server",1) %>%
```

```
  timeout(function() rexp(1,service_time))%>%
```

```
  release("server")
```

```
new_bank_queue %>%
```

```
  add_resource("server",3)%>%
```

```
  add_generator("customer",customer,function() rexp(1,cust_arrival))
```

```
## simmer environment: Bank Queue | now: 0 | next: 0
```

```
## { Monitor: in memory }
```

```
## { Resource: server | monitored: TRUE | server status: 0(3) | queue status: 0(Inf) }  
## { Source: customer | monitored: 1 | n_generated: 0 }
```

```
new_bank_queue%>%  
  run(until=480)
```

```
## simmer environment: Bank Queue | now: 480 | next: 482.19799420393  
## { Monitor: in memory }  
## { Resource: server | monitored: TRUE | server status: 2(3) | queue status: 0(Inf) }  
## { Source: customer | monitored: 1 | n_generated: 85 }
```

```
bank_3<-get_mon_arrivals(new_bank_queue)  
bank_3_resources<-get_mon_resources(new_bank_queue)  
bank_3$waiting_time<-(bank_3$end_time-bank_3$start_time-bank_3$activity_time)  
bank_3
```

##		name	start_time	end_time	activity_time	finished	replication
## 1	customer0	7.110369	8.473606	1.36323769	TRUE	1	
## 2	customer1	14.431114	15.835503	1.40438915	TRUE	1	
## 3	customer2	16.847266	20.001481	3.15421536	TRUE	1	
## 4	customer3	21.406463	22.080996	0.67453370	TRUE	1	
## 5	customer4	21.519863	25.017025	3.49716146	TRUE	1	
## 6	customer6	25.426425	26.356924	0.93049879	TRUE	1	
## 7	customer5	25.360497	27.251741	1.89124411	TRUE	1	
## 8	customer7	34.444067	37.495600	3.05153224	TRUE	1	
## 9	customer8	35.310549	38.436959	3.12641009	TRUE	1	
## 10	customer11	36.793471	41.375534	2.93857429	TRUE	1	
## 11	customer12	38.566593	41.795156	0.41962197	TRUE	1	
## 12	customer9	35.446861	43.210336	7.76347537	TRUE	1	
## 13	customer13	38.635982	43.369704	1.57454801	TRUE	1	
## 14	customer14	42.515932	43.522348	0.31201165	TRUE	1	
## 15	customer10	36.074055	44.843920	7.34832007	TRUE	1	
## 16	customer15	55.978816	65.407079	9.42826308	TRUE	1	
## 17	customer16	62.817621	65.451953	2.63433204	TRUE	1	
## 18	customer17	68.561421	68.798324	0.23690277	TRUE	1	
## 19	customer18	92.869510	99.256585	6.38707491	TRUE	1	
## 20	customer21	115.289331	115.541908	0.25257679	TRUE	1	
## 21	customer19	106.432524	117.098665	10.66614109	TRUE	1	
## 22	customer20	110.584569	127.109599	16.52502976	TRUE	1	
## 23	customer22	132.337564	133.753669	1.41610579	TRUE	1	
## 24	customer24	144.617466	145.428639	0.81117326	TRUE	1	
## 25	customer23	137.698501	147.478750	9.78024933	TRUE	1	
## 26	customer25	149.666913	152.222114	2.55520065	TRUE	1	
## 27	customer26	152.256333	156.890772	4.63443929	TRUE	1	
## 28	customer29	160.594580	161.007806	0.41322602	TRUE	1	
## 29	customer28	159.618145	165.206514	5.58836907	TRUE	1	
## 30	customer30	165.454117	167.108274	1.65415623	TRUE	1	
## 31	customer27	154.599713	178.099347	23.49963436	TRUE	1	
## 32	customer31	177.418390	181.094406	3.67601597	TRUE	1	

##	33	customer33	183.665515	183.729517	0.06400169	TRUE	1
##	34	customer32	179.310749	189.994753	10.68400421	TRUE	1
##	35	customer34	203.175541	208.902483	5.72694226	TRUE	1
##	36	customer36	213.319108	215.459014	2.13990601	TRUE	1
##	37	customer35	207.556178	216.537650	8.98147126	TRUE	1
##	38	customer37	222.313328	222.493153	0.17982439	TRUE	1
##	39	customer40	223.839434	227.430349	3.59091560	TRUE	1
##	40	customer38	222.896884	228.639281	5.74239725	TRUE	1
##	41	customer39	223.502050	230.044915	6.54286472	TRUE	1
##	42	customer42	234.553222	237.922736	3.36951368	TRUE	1
##	43	customer43	236.828651	242.651718	5.82306667	TRUE	1
##	44	customer41	233.324193	245.271727	11.94753404	TRUE	1
##	45	customer44	247.811963	251.477425	3.66546221	TRUE	1
##	46	customer46	253.351836	255.998415	2.64657883	TRUE	1
##	47	customer48	260.397509	273.966622	13.56911271	TRUE	1
##	48	customer45	252.533545	274.470897	21.93735264	TRUE	1
##	49	customer47	257.957727	278.749969	20.79224150	TRUE	1
##	50	customer49	277.702004	279.332457	1.63045352	TRUE	1
##	51	customer51	283.423031	285.556426	2.13339513	TRUE	1
##	52	customer50	279.928540	288.192612	8.26407191	TRUE	1
##	53	customer53	289.050043	289.948606	0.89856360	TRUE	1
##	54	customer52	288.978307	294.373336	5.39502841	TRUE	1
##	55	customer54	293.660937	294.719654	1.05871699	TRUE	1
##	56	customer55	305.230028	309.124126	3.89409751	TRUE	1
##	57	customer56	327.271993	328.196193	0.92419997	TRUE	1
##	58	customer57	329.357201	335.930741	6.57353993	TRUE	1
##	59	customer58	335.033553	339.023989	3.99043643	TRUE	1
##	60	customer59	348.022744	358.207728	10.18498348	TRUE	1
##	61	customer61	357.172413	358.730432	1.55801946	TRUE	1
##	62	customer60	352.196015	362.989436	10.79342046	TRUE	1
##	63	customer63	362.990814	363.788463	0.79764859	TRUE	1
##	64	customer62	359.847693	373.563226	13.71553373	TRUE	1
##	65	customer65	378.828202	380.639247	1.81104515	TRUE	1
##	66	customer64	375.402414	394.623705	19.22129040	TRUE	1
##	67	customer66	394.135846	395.326664	1.19081784	TRUE	1
##	68	customer68	412.802128	418.818701	6.01657361	TRUE	1
##	69	customer67	411.313344	425.896099	14.58275583	TRUE	1
##	70	customer69	415.048338	430.565189	15.51685125	TRUE	1
##	71	customer71	430.989363	431.108103	0.11873989	TRUE	1
##	72	customer73	432.692714	433.733853	1.04113926	TRUE	1
##	73	customer74	436.832935	438.892187	2.05925164	TRUE	1
##	74	customer72	432.551407	439.374410	6.82300300	TRUE	1
##	75	customer75	437.524881	439.672566	0.78037948	TRUE	1
##	76	customer77	444.429278	446.388064	1.95878669	TRUE	1
##	77	customer70	429.201455	446.725512	17.52405639	TRUE	1
##	78	customer78	452.318292	457.633203	5.31491162	TRUE	1
##	79	customer76	439.825732	458.289391	18.46365939	TRUE	1
##	80	customer79	458.407176	464.275045	5.86786901	TRUE	1
##	81	customer82	473.771326	476.478795	2.70746889	TRUE	1
##	82	customer80	473.541992	479.944547	6.40255494	TRUE	1

```
##      waiting_time
## 1  0.000000e+00
## 2  0.000000e+00
## 3  0.000000e+00
## 4  0.000000e+00
## 5 -1.332268e-15
## 6 -1.221245e-15
## 7  1.332268e-15
## 8 -3.552714e-15
## 9  3.552714e-15
## 10 1.643489e+00
## 11 2.808940e+00
## 12 -2.664535e-15
## 13 3.159174e+00
## 14 6.944037e-01
## 15 1.421544e+00
## 16 5.329071e-15
## 17 0.000000e+00
## 18 0.000000e+00
## 19 -5.329071e-15
## 20 1.387779e-15
## 21 -1.776357e-15
## 22 -3.552714e-15
## 23 -1.243450e-14
## 24 6.106227e-15
## 25 8.881784e-15
## 26 0.000000e+00
## 27 9.769963e-15
## 28 0.000000e+00
## 29 8.881784e-15
## 30 0.000000e+00
## 31 0.000000e+00
## 32 -3.108624e-15
## 33 0.000000e+00
## 34 0.000000e+00
## 35 1.776357e-15
## 36 0.000000e+00
## 37 -8.881784e-15
## 38 -2.359224e-15
## 39 7.105427e-15
## 40 8.881784e-15
## 41 -1.332268e-14
## 42 0.000000e+00
## 43 8.881784e-15
## 44 0.000000e+00
## 45 9.325873e-15
## 46 0.000000e+00
## 47 -2.842171e-14
## 48 -3.552714e-15
## 49 -1.421085e-14
```



```

## 50  0.000000e+00
## 51  0.000000e+00
## 52 -5.329071e-15
## 53  0.000000e+00
## 54  8.881784e-15
## 55 -1.110223e-14
## 56  2.664535e-15
## 57 -2.642331e-14
## 58  8.881784e-15
## 59  9.325873e-15
## 60  1.776357e-14
## 61 -6.661338e-15
## 62  2.842171e-14
## 63  0.000000e+00
## 64  2.842171e-14
## 65  0.000000e+00
## 66 -2.131628e-14
## 67  1.421085e-14
## 68  8.881784e-15
## 69 -1.953993e-14
## 70 -1.953993e-14
## 71 -1.698641e-14
## 72  0.000000e+00
## 73  0.000000e+00
## 74  8.881784e-15
## 75  1.367306e+00
## 76  0.000000e+00
## 77 -1.065814e-14
## 78  8.881784e-15
## 79 -1.065814e-14
## 80  8.881784e-15
## 81  0.000000e+00
## 82  8.881784e-15

```

bank_3_resources

##	resource	time	server	queue	capacity	queue_size	system	limit
## 1	server	7.110369	1	0	3	Inf	1	Inf
## 2	server	8.473606	0	0	3	Inf	0	Inf
## 3	server	14.431114	1	0	3	Inf	1	Inf
## 4	server	15.835503	0	0	3	Inf	0	Inf
## 5	server	16.847266	1	0	3	Inf	1	Inf
## 6	server	20.001481	0	0	3	Inf	0	Inf
## 7	server	21.406463	1	0	3	Inf	1	Inf
## 8	server	21.519863	2	0	3	Inf	2	Inf
## 9	server	22.080996	1	0	3	Inf	1	Inf
## 10	server	25.017025	0	0	3	Inf	0	Inf
## 11	server	25.360497	1	0	3	Inf	1	Inf
## 12	server	25.426425	2	0	3	Inf	2	Inf
## 13	server	26.356924	1	0	3	Inf	1	Inf

## 14	server	27.251741	0	0	3	Inf	0	Inf
## 15	server	34.444067	1	0	3	Inf	1	Inf
## 16	server	35.310549	2	0	3	Inf	2	Inf
## 17	server	35.446861	3	0	3	Inf	3	Inf
## 18	server	36.074055	3	1	3	Inf	4	Inf
## 19	server	36.793471	3	2	3	Inf	5	Inf
## 20	server	37.495600	3	1	3	Inf	4	Inf
## 21	server	38.436959	3	0	3	Inf	3	Inf
## 22	server	38.566593	3	1	3	Inf	4	Inf
## 23	server	38.635982	3	2	3	Inf	5	Inf
## 24	server	41.375534	3	1	3	Inf	4	Inf
## 25	server	41.795156	3	0	3	Inf	3	Inf
## 26	server	42.515932	3	1	3	Inf	4	Inf
## 27	server	43.210336	3	0	3	Inf	3	Inf
## 28	server	43.369704	2	0	3	Inf	2	Inf
## 29	server	43.522348	1	0	3	Inf	1	Inf
## 30	server	44.843920	0	0	3	Inf	0	Inf
## 31	server	55.978816	1	0	3	Inf	1	Inf
## 32	server	62.817621	2	0	3	Inf	2	Inf
## 33	server	65.407079	1	0	3	Inf	1	Inf
## 34	server	65.451953	0	0	3	Inf	0	Inf
## 35	server	68.561421	1	0	3	Inf	1	Inf
## 36	server	68.798324	0	0	3	Inf	0	Inf
## 37	server	92.869510	1	0	3	Inf	1	Inf
## 38	server	99.256585	0	0	3	Inf	0	Inf
## 39	server	106.432524	1	0	3	Inf	1	Inf
## 40	server	110.584569	2	0	3	Inf	2	Inf
## 41	server	115.289331	3	0	3	Inf	3	Inf
## 42	server	115.541908	2	0	3	Inf	2	Inf
## 43	server	117.098665	1	0	3	Inf	1	Inf
## 44	server	127.109599	0	0	3	Inf	0	Inf
## 45	server	132.337564	1	0	3	Inf	1	Inf
## 46	server	133.753669	0	0	3	Inf	0	Inf
## 47	server	137.698501	1	0	3	Inf	1	Inf
## 48	server	144.617466	2	0	3	Inf	2	Inf
## 49	server	145.428639	1	0	3	Inf	1	Inf
## 50	server	147.478750	0	0	3	Inf	0	Inf
## 51	server	149.666913	1	0	3	Inf	1	Inf
## 52	server	152.222114	0	0	3	Inf	0	Inf
## 53	server	152.256333	1	0	3	Inf	1	Inf
## 54	server	154.599713	2	0	3	Inf	2	Inf
## 55	server	156.890772	1	0	3	Inf	1	Inf
## 56	server	159.618145	2	0	3	Inf	2	Inf
## 57	server	160.594580	3	0	3	Inf	3	Inf
## 58	server	161.007806	2	0	3	Inf	2	Inf
## 59	server	165.206514	1	0	3	Inf	1	Inf
## 60	server	165.454117	2	0	3	Inf	2	Inf
## 61	server	167.108274	1	0	3	Inf	1	Inf
## 62	server	177.418390	2	0	3	Inf	2	Inf
## 63	server	178.099347	1	0	3	Inf	1	Inf

## 64	server	179.310749	2	0	3	Inf	2	Inf
## 65	server	181.094406	1	0	3	Inf	1	Inf
## 66	server	183.665515	2	0	3	Inf	2	Inf
## 67	server	183.729517	1	0	3	Inf	1	Inf
## 68	server	189.994753	0	0	3	Inf	0	Inf
## 69	server	203.175541	1	0	3	Inf	1	Inf
## 70	server	207.556178	2	0	3	Inf	2	Inf
## 71	server	208.902483	1	0	3	Inf	1	Inf
## 72	server	213.319108	2	0	3	Inf	2	Inf
## 73	server	215.459014	1	0	3	Inf	1	Inf
## 74	server	216.537650	0	0	3	Inf	0	Inf
## 75	server	222.313328	1	0	3	Inf	1	Inf
## 76	server	222.493153	0	0	3	Inf	0	Inf
## 77	server	222.896884	1	0	3	Inf	1	Inf
## 78	server	223.502050	2	0	3	Inf	2	Inf
## 79	server	223.839434	3	0	3	Inf	3	Inf
## 80	server	227.430349	2	0	3	Inf	2	Inf
## 81	server	228.639281	1	0	3	Inf	1	Inf
## 82	server	230.044915	0	0	3	Inf	0	Inf
## 83	server	233.324193	1	0	3	Inf	1	Inf
## 84	server	234.553222	2	0	3	Inf	2	Inf
## 85	server	236.828651	3	0	3	Inf	3	Inf
## 86	server	237.922736	2	0	3	Inf	2	Inf
## 87	server	242.651718	1	0	3	Inf	1	Inf
## 88	server	245.271727	0	0	3	Inf	0	Inf
## 89	server	247.811963	1	0	3	Inf	1	Inf
## 90	server	251.477425	0	0	3	Inf	0	Inf
## 91	server	252.533545	1	0	3	Inf	1	Inf
## 92	server	253.351836	2	0	3	Inf	2	Inf
## 93	server	255.998415	1	0	3	Inf	1	Inf
## 94	server	257.957727	2	0	3	Inf	2	Inf
## 95	server	260.397509	3	0	3	Inf	3	Inf
## 96	server	273.966622	2	0	3	Inf	2	Inf
## 97	server	274.470897	1	0	3	Inf	1	Inf
## 98	server	277.702004	2	0	3	Inf	2	Inf
## 99	server	278.749969	1	0	3	Inf	1	Inf
## 100	server	279.332457	0	0	3	Inf	0	Inf
## 101	server	279.928540	1	0	3	Inf	1	Inf
## 102	server	283.423031	2	0	3	Inf	2	Inf
## 103	server	285.556426	1	0	3	Inf	1	Inf
## 104	server	288.192612	0	0	3	Inf	0	Inf
## 105	server	288.978307	1	0	3	Inf	1	Inf
## 106	server	289.050043	2	0	3	Inf	2	Inf
## 107	server	289.948606	1	0	3	Inf	1	Inf
## 108	server	293.660937	2	0	3	Inf	2	Inf
## 109	server	294.373336	1	0	3	Inf	1	Inf
## 110	server	294.719654	0	0	3	Inf	0	Inf
## 111	server	305.230028	1	0	3	Inf	1	Inf
## 112	server	309.124126	0	0	3	Inf	0	Inf
## 113	server	327.271993	1	0	3	Inf	1	Inf

## 114	server	328.196193	0	0	3	Inf	0	Inf
## 115	server	329.357201	1	0	3	Inf	1	Inf
## 116	server	335.033553	2	0	3	Inf	2	Inf
## 117	server	335.930741	1	0	3	Inf	1	Inf
## 118	server	339.023989	0	0	3	Inf	0	Inf
## 119	server	348.022744	1	0	3	Inf	1	Inf
## 120	server	352.196015	2	0	3	Inf	2	Inf
## 121	server	357.172413	3	0	3	Inf	3	Inf
## 122	server	358.207728	2	0	3	Inf	2	Inf
## 123	server	358.730432	1	0	3	Inf	1	Inf
## 124	server	359.847693	2	0	3	Inf	2	Inf
## 125	server	362.989436	1	0	3	Inf	1	Inf
## 126	server	362.990814	2	0	3	Inf	2	Inf
## 127	server	363.788463	1	0	3	Inf	1	Inf
## 128	server	373.563226	0	0	3	Inf	0	Inf
## 129	server	375.402414	1	0	3	Inf	1	Inf
## 130	server	378.828202	2	0	3	Inf	2	Inf
## 131	server	380.639247	1	0	3	Inf	1	Inf
## 132	server	394.135846	2	0	3	Inf	2	Inf
## 133	server	394.623705	1	0	3	Inf	1	Inf
## 134	server	395.326664	0	0	3	Inf	0	Inf
## 135	server	411.313344	1	0	3	Inf	1	Inf
## 136	server	412.802128	2	0	3	Inf	2	Inf
## 137	server	415.048338	3	0	3	Inf	3	Inf
## 138	server	418.818701	2	0	3	Inf	2	Inf
## 139	server	425.896099	1	0	3	Inf	1	Inf
## 140	server	429.201455	2	0	3	Inf	2	Inf
## 141	server	430.565189	1	0	3	Inf	1	Inf
## 142	server	430.989363	2	0	3	Inf	2	Inf
## 143	server	431.108103	1	0	3	Inf	1	Inf
## 144	server	432.551407	2	0	3	Inf	2	Inf
## 145	server	432.692714	3	0	3	Inf	3	Inf
## 146	server	433.733853	2	0	3	Inf	2	Inf
## 147	server	436.832935	3	0	3	Inf	3	Inf
## 148	server	437.524881	3	1	3	Inf	4	Inf
## 149	server	438.892187	3	0	3	Inf	3	Inf
## 150	server	439.374410	2	0	3	Inf	2	Inf
## 151	server	439.672566	1	0	3	Inf	1	Inf
## 152	server	439.825732	2	0	3	Inf	2	Inf
## 153	server	444.429278	3	0	3	Inf	3	Inf
## 154	server	446.388064	2	0	3	Inf	2	Inf
## 155	server	446.725512	1	0	3	Inf	1	Inf
## 156	server	452.318292	2	0	3	Inf	2	Inf
## 157	server	457.633203	1	0	3	Inf	1	Inf
## 158	server	458.289391	0	0	3	Inf	0	Inf
## 159	server	458.407176	1	0	3	Inf	1	Inf
## 160	server	464.275045	0	0	3	Inf	0	Inf
## 161	server	473.541992	1	0	3	Inf	1	Inf
## 162	server	473.640983	2	0	3	Inf	2	Inf
## 163	server	473.771326	3	0	3	Inf	3	Inf

## 164	server	476.478795	2	0	3	Inf	2	Inf
## 165	server	476.936675	3	0	3	Inf	3	Inf
## 166	server	479.944547	2	0	3	Inf	2	Inf
##	replication							
## 1		1						
## 2		1						
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```

## 147          1
## 148          1
## 149          1
## 150          1
## 151          1
## 152          1
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## 161          1
## 162          1
## 163          1
## 164          1
## 165          1
## 166          1

avg_waiting_time <- mean(bank_2$waiting_time)
cat("Average Waiting Time:", avg_waiting_time, "minutes\n")

## Average Waiting Time: 0.8286407 minutes

avg_queue_length<- mean(bank_2_resource$queue)
cat("Average queue Length:", avg_queue_length, "customers\n")

## Average queue Length: 0.2138365 customers

server_utilization<- 10/(2*12)

cat("Server utilization", server_utilization*100,"%")

## Server utilization 41.66667 %


average_waiting_time_3<-mean(bank_3$waiting_time)
cat("Average Time when have 3 severs",average_waiting_time_3,"miniutes\n")

## Average Time when have 3 severs 0.1353031 miniutes

average_queue_time<-mean(bank_3_resources$queue)
cat("Average Queue length",average_queue_time,"customers\n")

## Average Queue length 0.06024096 customers

server_utilization_3<- 10/(3*12)
cat("Server utilization", server_utilization_3*100,"%")

## Server utilization 27.77778 %

```


Analysis and Interpretation

Performance Analysis of the Current System

In the bank environment with two servers the average waiting time of the customers is found to be 0.8286407 minutes, which is roughly 50 seconds, which is relatively low, and suggests a relatively smooth flow of customers without having a delay. Average queue length of 0.21 customers suggests that a customer rarely have to be in the queue. Furthermore 41.6% of server utilization suggests that for the whole 8 hours each server is utilized only up to 41.6%, suggesting that there might be times when no customers were served to a server.

Impact of Adding a Third Server

With the introduction of one more server to the environment results in a dropping average waiting time to 0.13 minutes, which is roughly 8 seconds this, the average queue length to 0.0602 customers suggesting that the system is having a way more smooth customer flow while having less delay and an even less crowded environment relative to the initial system with two servers. Server utilization drops to 27.77% suggesting that there might be more times when no customers were served to a server is comparatively high resulting in an underutilization of servers.

Operational strategy.

Improve customer experience

Since the customer arrivals in this system are based on poison distribution with a lambda value (customers per hour) of 10 the probability of even having 20 customers per hour is 0.01866 which is very low.

$$P(X = k) = \frac{e^{-\lambda} \lambda^k}{k!}$$

In the above case $\lambda=10$ and $k=20$

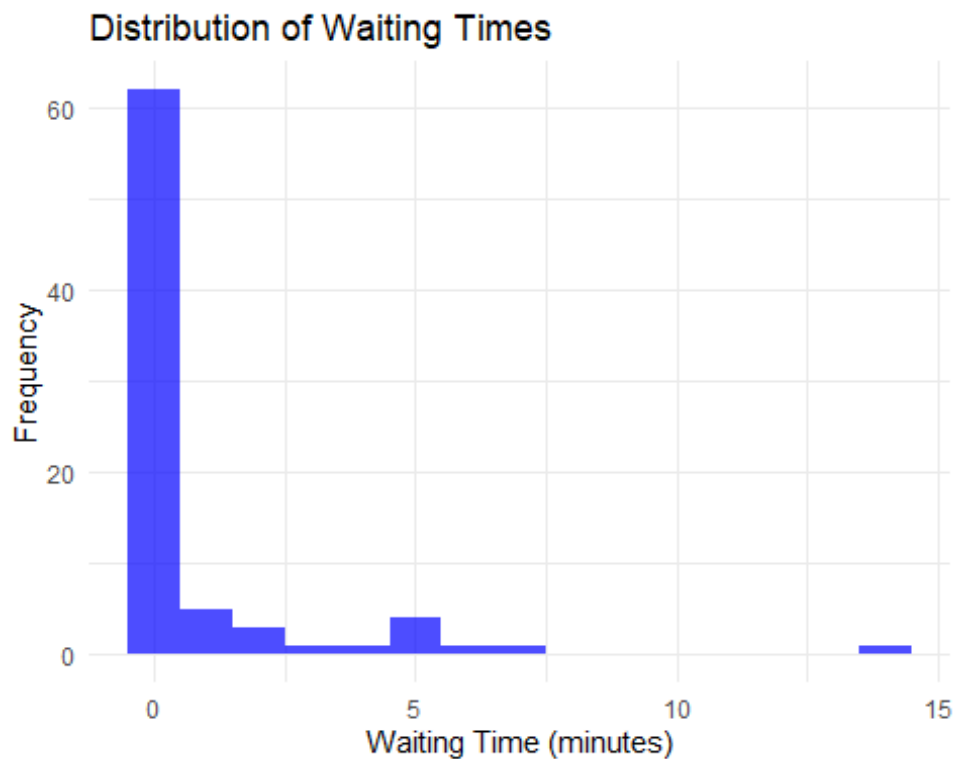
But in the real world problems these values can be fluctuate to higher values especially in peak hours, and since the service time is in a exponential distribution and which is five minutes per customer with a lambda value of 0.2, **by the cumulative distribution function, probability of customer being served in 5 minutes will be 0.62 indicates that there is a 0.38 probability of customer to take more time than 5 minutes.** Under these conditions having a third server would be beneficial for the bank, especially during peak hours, to manage the crowd and in order to provide a good service for the customers.

Cost of having 3rd server

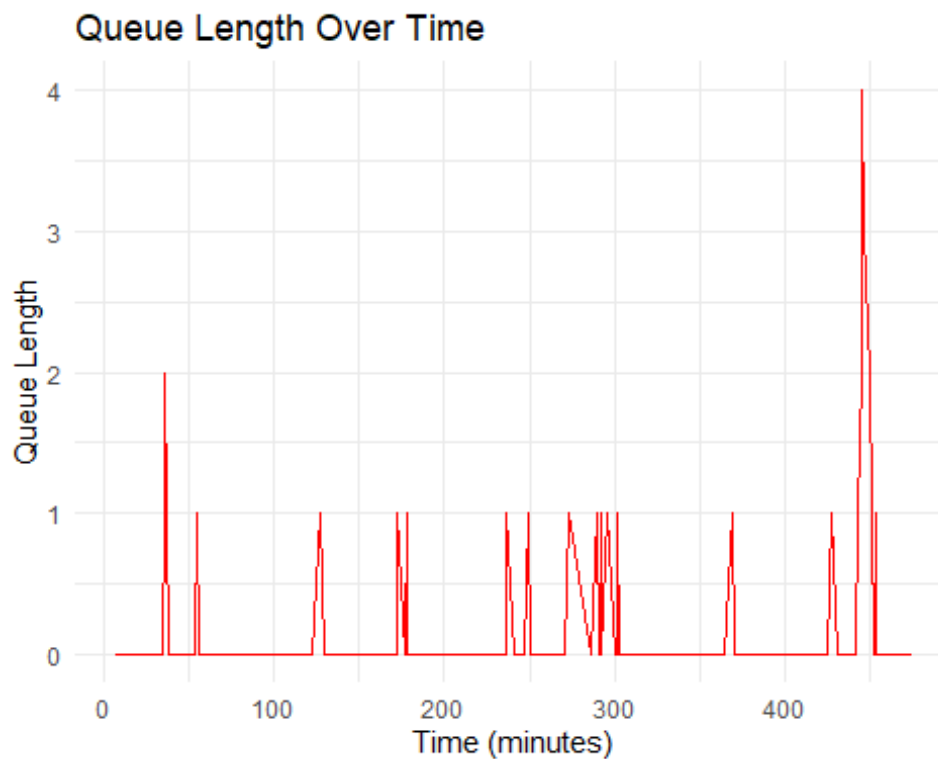
Even though the addition of a 3rd server could significantly improve in customer experience, at the same time server utilization of the system decreased to a very low value of 41.6% to 27.7%, suggesting that the servers would underutilize, which leads servers to have more idle time without being used by a customer. This underutilization suggests that the cost of adding a third server may not give its expected benefits, making it a potentially inefficient investment for this scenario, but in the real-world use have high rate of customer flow especially in peak hours might increase the server utilization. Therefore, adding an extra server to the system might be beneficial for the bank.

```
library(ggplot2)

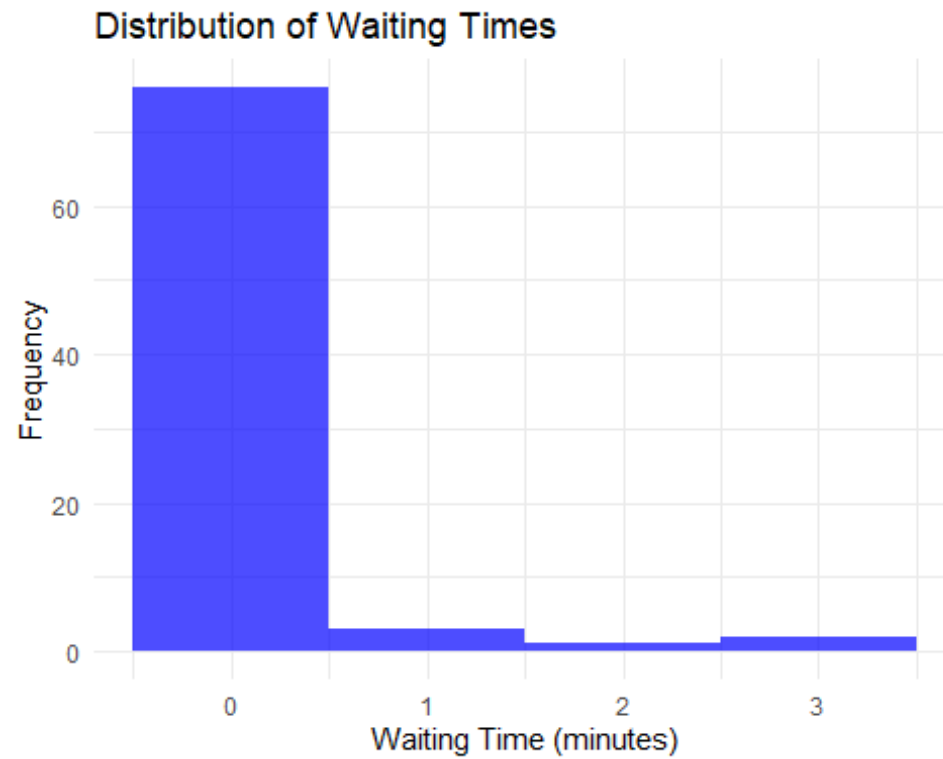
ggplot(bank_2, aes(x = waiting_time)) +
  geom_histogram(binwidth = 1, fill = "blue", alpha = 0.7) +
  theme_minimal() +
  labs(title = "Distribution of Waiting Times", x = "Waiting Time (minutes)",
       y = "Frequency")
```



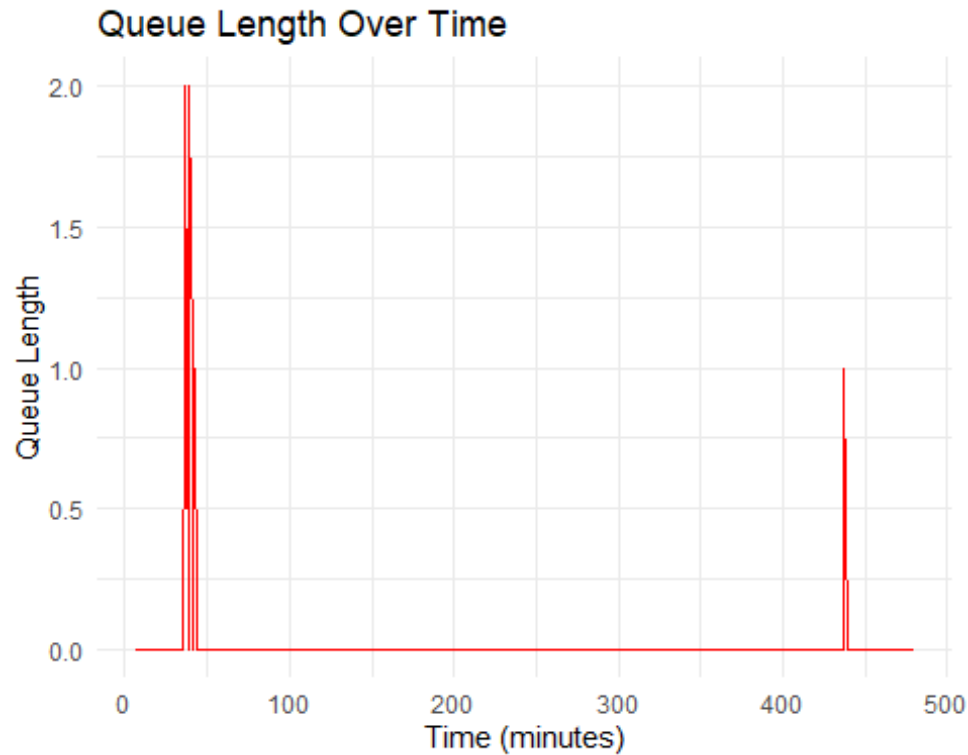
```
ggplot(bank_2_resource, aes(x = time, y = queue)) +
  geom_line(color = "red") +
  theme_minimal() +
  labs(title = "Queue Length Over Time", x = "Time (minutes)", y = "Queue
Length")
```



```
ggplot(bank_3, aes(x = waiting_time)) +
  geom_histogram(binwidth = 1, fill = "blue", alpha = 0.7) +
  theme_minimal() +
  labs(title = "Distribution of Waiting Times", x = "Waiting Time (minutes)",
y = "Frequency")
```



```
ggplot(bank_3_resources, aes(x = time, y = queue)) +  
  geom_line(color = "red") +  
  theme_minimal() +  
  labs(title = "Queue Length Over Time", x = "Time (minutes)", y = "Queue  
Length")
```



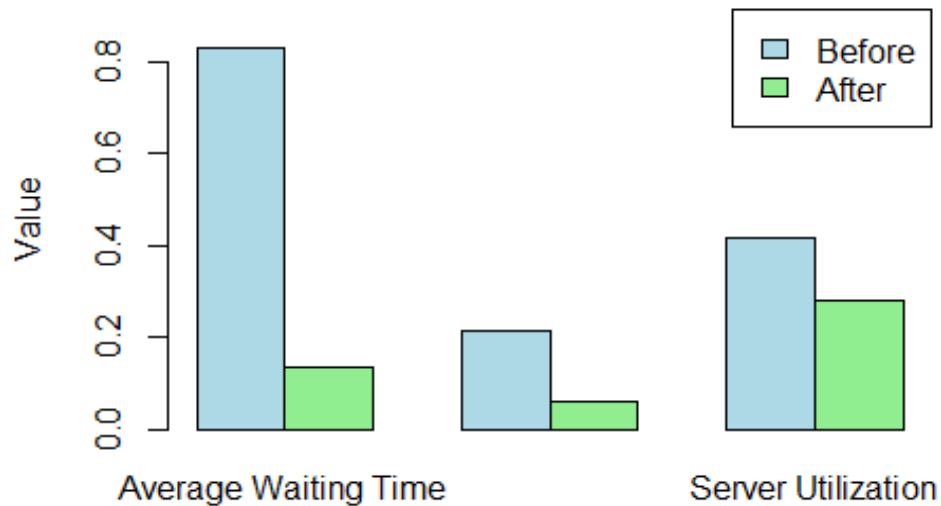
```
metrics <- c("Average Waiting Time", "Average Queue Length", "Server
Utilization")
before <- c(avg_waiting_time, avg_queue_length, server_utilization)
after <- c(average_waiting_time_3, average_queue_time, server_utilization_3)

df <- data.frame(Metrics = metrics, Before = before, After = after)

bp <- barplot(t(as.matrix(df[, 2:3])), beside = TRUE,
              names.arg = df$Metrics, col = c("lightblue", "lightgreen"),
              main = "Comparison of Key Metrics Before and After Adding a
Server",
              ylab = "Value", ylim = c(0, max(c(before, after)) * 1.1))

legend("topright", legend = c("Before", "After"), fill = c("lightblue",
"lightgreen"))
```

Comparison of Key Metrics Before and After Adding a Server



3. Visualization and Reporting

Methodology

Designed a stimulation environment for a bank in order to evaluate the system performance.

The system was operating under some conditions such as, arrival rate of customers are in a poisson distribution with an average rate of 10 customers per hour. Service time of the system follows an Exponential distribution with an average service time of 5 minutes per customer. The queue is formed with the queueing principle of First come first serve with a 480 minutes of stimulation time. Simmer built in library was used for the discrete event stimulation.

Two systems were modeled according to the above conditions.

1. A system with 2 servers.
2. A system with 3 servers.

By using the trajectory () function initiated the customers flow, each and every customer is directed to a one server. After directing a server each customer spends some time being served which is decided by a service time which is behaving according to an exponential distribution. After completing the actions, the customer will be released from the server by release () function in order to make it available for others.

In both cases by get_mon_arrival() and get_mon_resource() was used to extract arrival data and resource data.

For these two systems, performance was calculated by using three metrics, such as

1. Average waiting time- This was calculated by using start time, end time and activity time. With the equation of

$$\text{waiting time} = \text{Start time} - \text{end time} - \text{activity time}$$

2. Average queue length- was calculated by the mean value of the queue column of the resource usage data.
3. Server utilization- This was calculated by using the average rate of customer arrival and the service time of server which are 10 customers per hour and 5 minutes per customer. Therefore, from service time the number of customers served per hour can be calculated as 12 customers per hour

$$\text{Server utilization} = \frac{\text{Arrival rate of customers}}{(\text{number of servers} * \text{number of customers served per hour})}$$

Results

These three performance measures describe the behavior of both the stimulation environment and provide a clear detailed idea about the environment.

Key performance metrics	2 servers	3 servers
Average waiting time	0.8286407	0.1353031
Average Queue length	0.2138365	0.06024096
Server utilization	41.66667%	27.77778%

By comparing these values, it is clear that after the addition of the new server customers experience has improved because of the drop in waiting time by 41 seconds which but the addition of the new server server utilization was dropped by drastically which is 14% meaning each server spends a significant amount of time idle.

Recommendation

Although the addition of a 3rd server might improve the user experience in peak hours, meanwhile it decreases the server utilization and raises concerns about the cost

effectiveness of the system. Therefore, alternative methods can be used to overcome this problem.

1. Using the third server only when the queue length is very high.