ORIE 5580

Project Report

on

Redesigning the Repair Network of Toner It Down! Inc.

Submitted by: Group 3

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Executive summary

This report contains a preliminary study on redesigning TonerItDown Inc.'s repair network in Syracuse area. Area management is not happy with the performance of the repair network. They believe competitors' ability to serve much faster poses a real threat to the company's market share in this area.

In this study, we have done a simulation study to understand the most economic staffing required (in terms of technicians and vehicles) in order to meet competitor's service level. We have limited scope on only one model of copiers that are used in 10 business centers in Syracuse area. As discussed with area management, we have used two key business metrics to define target service levels. These are:

- Time between customer call and mechanic reaching there. (less than 1 hour)
- Time between customer call and a functional copier being installed. (less than 3 hour)

Both of these metrics are directly related to the staffing level. After gathering required inputs via historical data, employees and management interviews, we build a simulation model to arrive at a staffing level of 22 technicians (with 13 cars) and 8 Drivers (with 5 vans). Following budget will be required to fund this staffing:

- **total annual budget of $3.2-$3.4 million** for first year,
- **total annual budget of $2.1-$2.5 million for subsequent years** (subjected to asset depreciation and normal growth rate)

We found this most economic way to achieve target service levels subjected to real world constraints like traffic variability, employee load management, variability in processing times etc.

As we discuss in this report, we have done the due diligence to ensure model validation and accuracy. Further, we have looked at variation in operating parameters to understand the sensitivity of this solution. Finally, this simulation model is designed to be extensible to consider multiple copier models and multiple locations to study more complex and intertwined systems.

Problem description

Syracuse area management is not happy with the performance of the repair network in terms of time it takes today to address customer requests. Given superior customer service levels, their competitors are marching to eat into the company's market share in this area. Although there can be other ways to approach this situation (in terms of pricing, product quality etc.), we are assuming that improving response times is the most sustainable way to address the current threat.

After initial analysis, we have arrived at two key metrics that we believe are key to improving customer experience with respect to the repair process. These are:

- Time between customer call and mechanic reaching there. (than 1 hour)
- Time between customer call and a functional copier being installed. (less than 3 hours)

Note that we have ample reasons to believe that they are doing their best for on-site diagnosis and on-site repair times - these times cannot be further reduced. So, only component that has a scope of improving is initial response time. (on-site repairs = initial response time+on-site diagnosis time+on-site repair time).

We can ofcourse, throw money at the problem and keep increasing the resources (in terms of technicians and vehicles), however that would not be sustainable. In addition to high costs, low utilization (in case of over hiring) will cause high employee turnover. Hence, we need to **arrive at an optimal level of staffing to balance between service levels and costs subjected to current process and other real life constraints.**

In this study, we are looking to follow current process of customer request redressal. There might be some latent opportunity areas in current process - but that's out of scope of this study. We have replicated following process in our solution:

1. The customer request is received at the dispatch center.
2. A repair mechanic is dispatched to the customer location.
3. The repair mechanic travels to the customer location from current location.
4. He/she diagnoses the problem. If he/she can fix the problem on-site, he/she does so and the customer request marked resolved.

5. If the mechanic cannot fix the problem on-site, the copier needs to be replaced with a new one and the broken copier has to be taken to the Dispatch Center where it can be repaired.
6. For this purpose, the mechanic calls the dispatch center to request a van.
7. The van (and driver) replaces the broken copier at the customer location with one of the working copiers stored at the dispatch center.

Now, In this setting, we had to consider constraints posed in real world. We have duly taken into account following constraints while analysing our simulation results:

- Employee amenities:
    - Employees work for max 9 hours a day with 1 hour break in between their shifts.
    - They might take leave, late to work, fall sick etc. - assuming all these factors, we have maintained employee utilization to near 85%. This will allow some employees to fill for others as and when required.
    - Technicians travel in company car for initial diagnosis and on site repair process. Drivers ferry around vans to exchange copier machines that need replacement.
- Vehicle availability:
    - Vehicles (both technician cars and vans) may break down from time to time.
    - Shifts changeover might mean not all vehicles are available at the start of shift.
- Process time variations:
    - Process time might change from time to time. These variations are modelled as different statistical distribution rather than being taken as an average number.
- External factors:
    - External factors such as traffic or construction etc. my have an impact on travel times - which we are mindful of.

Taking all of these factors into account, we have put special emphasis on model validation and accuracy. As discussed in the following sections, we have taken 3 pronged approach to establish model accuracy. Finally we have arrived at a robust solution which is reasonably sensitive to foreseeable changes in input parameters and operational environment.

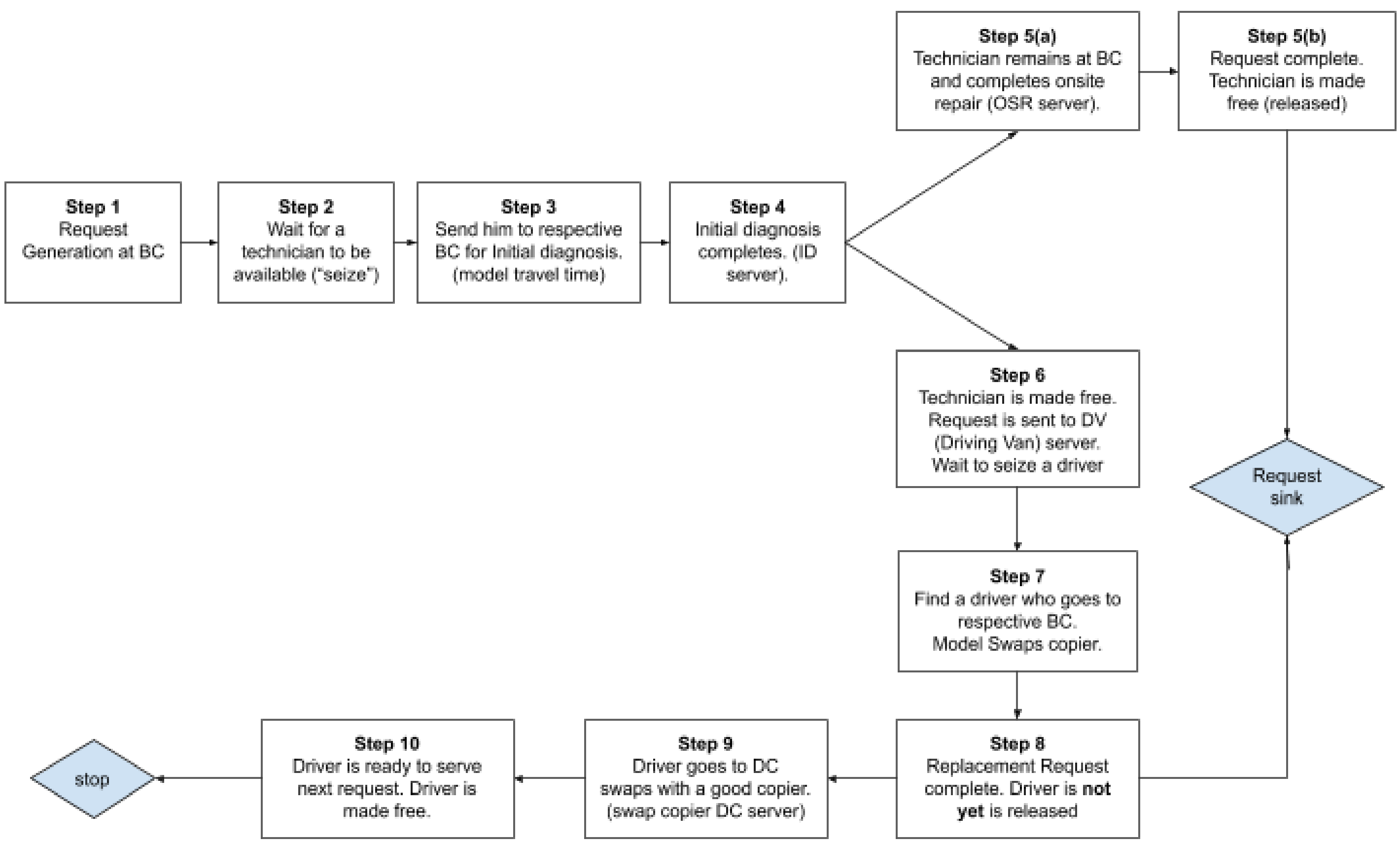
Modeling approach and assumptions

Simulation approach

There are two approaches that could have been taken to solve problem at hand:

1. Setting it up as an optimization problem with some objective function which is subjected to constraints.
2. Setting it up as a simulation problem, actually observing how the process plays out in real time.

We have taken the second approach, as it gives significant visibility into solution's working and given a package like Simio, it also gives rich front end to observe system playing out in a fast track manner. This is quite useful to sense if something is wrong (e.g. at one business center requests keep accumulating). Following process flow diagram summarizes simulation approach:



Building on the above process, the following considerations are made to the model:

- Locations:
  - 1 DC (Distribution Center)- Where all good copiers are stocked.
  - 10 Business Center (BC)
- Workers: 2 set of workers:
  - Mechanics: Who do initial diagnosis and onsite repairs.
  - Drivers: Who carry out copy swapping in case on site. Each time they need to go back to DC to swap faulty copier with a good copier, so that they are ready for the next request.
- Work schedule:
  - As requests can come throughout 24 hours, we need to have workers in three shifts - morning, evening and late night.
- Vehicles:
  - Mechanics need to move in Car. Drivers moves in Vans which has enough space to carry one copier at a time.
  - We have not considered vehicles as an independent entity in our model. Number of vehicles required is simply taken as max number of concurrent workers.
  - Further a cost split between Vehicles and Workers is assumed to arrive at an economic value of a configuration.
- Network:
  - These entities can move among DC and business centers at predefined paths. Each section of which has defined speed and distance.
- Business objectives:
  - As discussed above we are simulating to find out number of workers and vehicles required to ensure performance levels for initial response times (less than 1 hour) and replacement time (less than 3 hours).

Experiments

An “Experiment” is defined as running simulation model for a given configuration of set of operational parameters. These parameters can be number of technicians in different shifts, number of drivers, processing times, travel times etc. A experiments consists of about 100 replications to arrive at statistically significant range of outputs metrics.

Once a base model was established we carried out 100+ experiments as part of result analysis to understand the impact of various operational parameters on different output Metrics. Between two experiments, we change either change only one parameter to learn isolated impact of that parameter or we can change a set of parameters to understand combined impact.

Key Assumptions

Following key assumptions went in to the model:

Assumptions from business side:

- Reducing response time is most sustainable to improve customer experience and hence retain market share.
- On-site diagnosis and on-site repair times can not be improved further.
- Constraints on employee amenities (max working hours, break time, leaves, breakdowns etc) will limit worker utilization to 85%.
- Processing times for different activities (Initial diagnosis, on site repair etc) follows historical distributions.
- On shift change, every mechanic starts from the dispatch center

Assumptions to limit the scope of the problem:

- TIDInc has an ample supply of spare copiers at the dispatch center. This allows to keep modelling of inventory out of scope of the current problem.
- Every business center uses the same type of copier.
- Two seperate groups of workers - Technicians and Drivers are considered. Interchanging between these groups is ignored due to different skill sets and costs.
- Number of vehicles required = Max workers requires in a shift + One additional vehicle.
- One additional vehicle will take care of overlap during shift changeover time and vehicle breakdowns.
- Cost split between vehicle and workers (to calculate economic cost for a given configuration):
    - Total cost of 140K for Car + Mechanic (40k Car + 100K mechanic salary)
    - Total cost: 100K for Van + Driver (50K Van + 50K Driver salary)

Assumptions due to lack of data:

- A rather simplified distribution for swapping times has been assumed due to lack of historic data.

Model verification

We have done model verification at three levels. These gives us high confidence on model accuracy and validation. These levels are:

1. Converging two independent models.
2. Comparing output metrics with an approximate system
3. Directional tests

Level 1: Converging two independent models

We developed two independent models with very different implementation logics. We have discussed first model above. For the second model, we vary the capacities (quantity of requests a server can process) of different locations in real time to model worker availability. We use explicit data tables to provide travel time and speeds among different entities - rather than defining a network as in first model. Further second model assume workers to be available throughout the day - which is essentially the same as having the same number of workers employed across all shifts.

For the same set of configs both models compute quite the same output metrics. One of such comparisons is as follows:

	# of technicians (in all shifts)	# of drivers (in all shifts)	Initial response time (mins)	Server replacement time (hours)
Model 1	9	4	55.59	2.74
Model 2	9	4	55.78	2.78

Difference can be attributed to the fact that in the second model workers are restricted to move within a cluster of nearby business centers, where as in the first model there is no such restriction.

Level 2: Comparing output metrics with an approximate system

We developed a simple “Average” model combining all business centers into one center. This average version help us to perform a sanity check of the system. We take an average time of travelling among different combination of business centers, between business centers and distribution center. The initial diagnosis service time is a weighted average of the means of the business centers with differing service rates. Swapping time, On site repair times and replacement probability is the same for all business center anyways.

	# of technicians (in all shifts)	# of drivers (in all shifts)	Initial response time (mins)	Server replacement time (hours)
Model 1	9	4	55.59	2.74
“Average Model”	9	4	46.0	3.3

Ofcourse, this “Average” model is not very accurate but it gives us confidence that our selected model is in the same ballpark.

Level 3: Directional tests

Next we conducted some logical directional tests to ensure our model react to change in input parameters in an expected way. Please note that in each case it may not be possible to predict output behaviour due to two or more opposing impacts.

Test	Expected output	Pass test?
Increase the number of technicians	Decrease in initial response time	Yes
	Decrease in replacement time	Yes

	Decrease in technician utilization	Yes
Increase the number of driver	Decrease in initial response time	Yes
	Decrease in replacement time	Yes
	Decrease in driver utilization	Yes
Increase in request generation rate	Increase in initial response time	Yes
	Increase in replacement time	Yes
Increasing the Initial Diagnosis	Increase in initial response time	Yes
	Increase in replacement time	Yes
Increasing the On Site Repair Time	Increase in initial response time (as technician will be spend more time on an request)	Yes
	Increase in replacement time(due to increased initial response time)	Yes
Increasing the travel speeds	Decrease in initial response time	Yes
	Decrease in replacement time	Yes
On site probability dropped to zero	Decrease in initial response time	Yes
On site probability to 100%	Decrease in initial response time	Yes
	No Replacement case	Yes
Increasing swapping time	No change in initial response time	Yes
	Decrease in replacement time	Yes

Data analysis

Input analysis

We input analysis we relied on historical service data, employee interviews and management interview. Wherever historic data was available, we carried out due tests to ensure probability distributions we are using are statistically significant for 95% confidence. Some of the key insights we arrived at:

- Upon analysing request arrival rates, we learnt that requests come 24 hours a day. This might be because of some of clients working in shifts. This is a significant impact on how we approach the problem. We have created 3 shifts and number of mechanics and drivers are looked at these shift level. So as to avoid low utilization.
- Contribution of different business centers to overall requests is not the same. We suspect it is proportional to the total number of copier these business centers have on an average.
- Percentage of requests needing repair and On site repair times were found to be having the same distribution for all BCs, which gives comfort that there is no BC specific issue in copiers.
- Initial diagnosis time: We have found it to be different for two different groups of business centers. One group is (1,4,5,6,7,8,10) and the second group is (2,3,9). On further probing, we learnt that BC 2,3 and 9 are located inside malls which need additional time for parking, security, elevators etc.
- In addition to the available data sources, we also interviewed employees to understand loading and unloading times further.

Model analysis

Arriving at a solution

Once we established, model is accurate and is behaving as expected, we went on to find an optimum solution. We did this by evaluating various configurations and then arriving at ones that meet business objectives. For this we have used used an in-built automated utility in our package - which evaluated more than 1000+ configurations to arrive at an optimal configuration. Some of the close to optimal configurations are:

Sr.no.	Option 1	Option 2	Option 3	Option 4
Technician in morning shift	11	11	13	12
Technician in evening shift	8	9	8	8
Technician in late night shift	2	2	2	2
Drivers in morning shift	3	3	3	3
Drivers in evening shift	4	4	4	4
Drivers in late night shift	1	1	1	1
Budget (in '000 Dollars)	3140	3240	3280	3240
Initial response time	59.2	55.0	54.6	54.8
Replacement time	2.8	2.8	2.8	2.8
Morning shift technician utilization	93.8	93.7	88.4	87.6
Evening shift technician utilization	83.8	76.1	80.7	80.2
Last night shift technician utilization	77.0	76.3	77.0	77.0
Morning shift driver utilization	60.3	61.0	62.2	69.8
Evening shift driver utilization	46.9	47.8	45.2	53.3
Last night shift driver utilization	36.8	34.3	34.7	41.4

*See appendix for more details.

- Out of these, we have to reject option 1, as it does not meet the 95% confidence interval level test for Initial response time.
- Among Option 2, Option 3 and Option 4 - all three support business goals with 95% confidence. However Option 3 is dropped as its most costly among three options.
- In order to address real life constraints discussed above, we are using guiding worker utilization in all shifts to be around 85%. Finally we calculated number of vehicles

required as discussed above. With this in mind, option 4 outweighs option 2, as utilization levels are more balanced in option 4. Hence option 4 is recommended option.

Sensitivity Analysis

We further looked at the robustness of our recommended solution. Here, we increase/decrease each input variable, one at a time, and evaluate at what point does either of business objective of initial response time (more than 60 mins) or replacement time (more than 3 hours) or both violates.

Parameter	Recommended configuration	Breaking point (keeping other parameters constant)
# of morning worker	12	10
# of evening worker	8	7
# of night worker	2	1
# of morning driver	3	1
# of evening driver	4	3
# of night driver	1	0
Increase in Need Replacement Probability	0.18	0.22
Decrease in Need Replacement Probability	0.18	0
Average rate of request	Current distribution in appendix	Baseline shift of 3% more than current
Average On Site Repair Processing time	Current distribution in appendix	Baseline shift of 6% more than current.
Average initial diagnosis time	Current distribution in appendix	Baseline shift of 7% more than current.
Average swap time at DC	Current distribution in appendix	Baseline shift of 11% more than current.

Average swap time at Business center	Current distribution in appendix	Baseline shift of 11% more than current.

*Baseline shift is the change required in whole distribution, variation with same baseline distribution is already accounted for.

An interesting observation was made when the Onsite Repair Prob shot to 1 and replacement to 0, the configuration still holds business goals - effectively immune to increase in on site repair probability.

Recommendation & Conclusion

Our recommendation is to have the following configuration in Syracuse area:

	Morning	Evening	Late night
Number of Technicians	12	8	2
Number of Van drivers	3	4	1
Number of Cars	13		
Number of Vans	5		

This is the most economic and feasible configuration in terms of staffing capacity. This configuration will cost **about $3.2-$3.4 million for first year** and then about **$2.1-$2.5 million for each subsequent year** (subjected to asset depreciation and normal growth rate). This configuration will allow us to meet business goals of having initial response times less than 1 hour and replacement times within 3 hours.

Having said that, we think following are the next steps towards developing this solution:

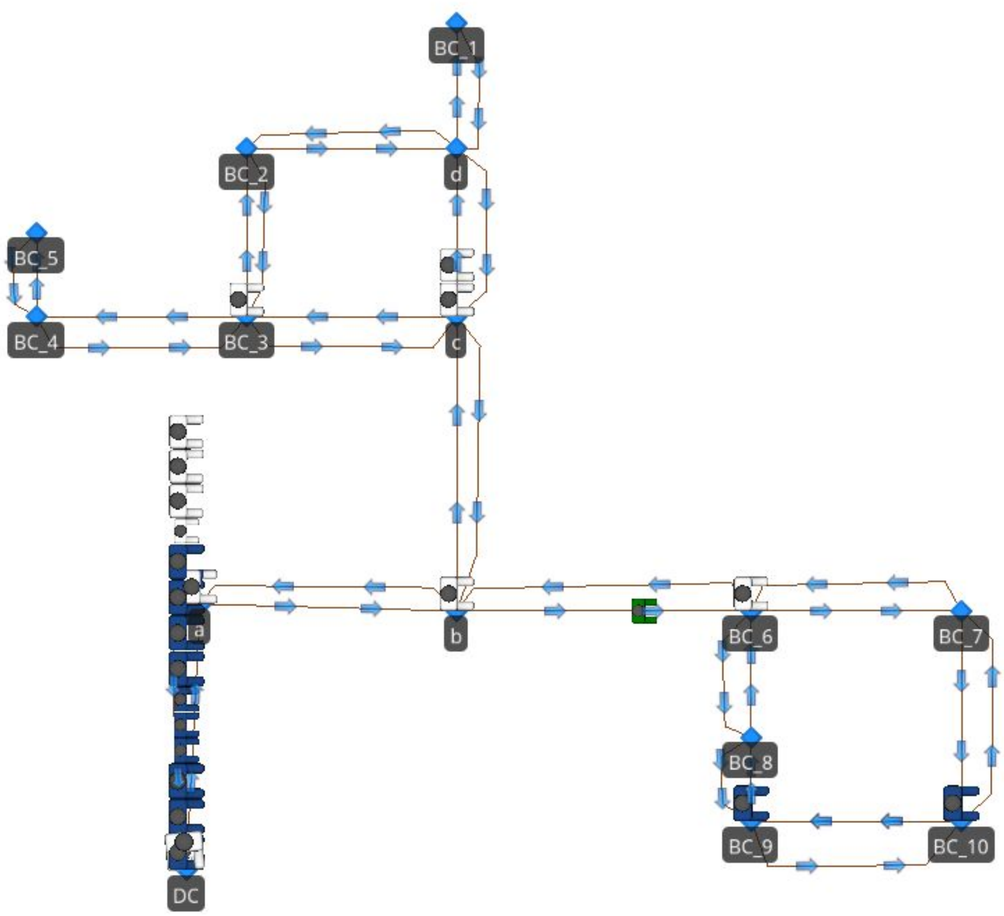
- Doing field testing to ensure model predictions match ground actualities. This can be done by having a new configuration tested in field for 2-3 weeks and see simulation model is able to predict the performance.

- Expanding this simulation model to multiple copier types.
- Expanding this simulation model to include employee level attributes.
- Improving data collection on swapping times at DC and Business center.

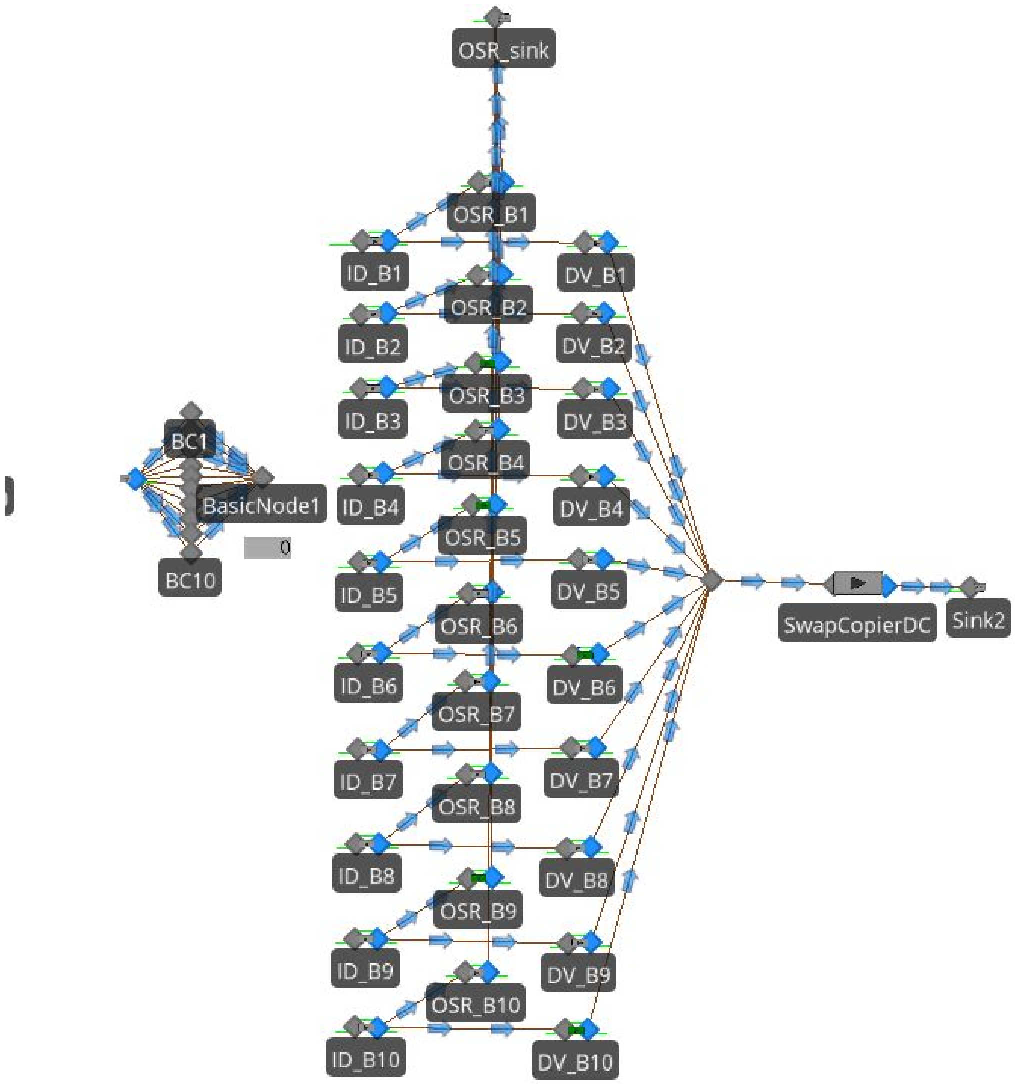
Appendix

Simulation Model implementation

Model is implemented in simio package. It has primarily two components: Frontend and Backend. Frontend of the model is basically a visualization part, where we can see different entities moving around, working at business centers, waiting at DC, queues etc. Let us look at implementation in simio screenshots to set the context. Then we will go into details of each step and look at implementation logic.



Backend of the model is where all logic resides and magic happens. In simio, backend of model have the following structure:

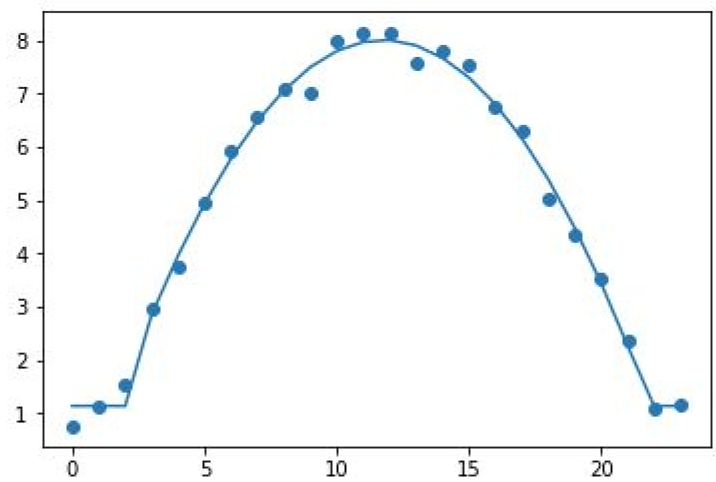


Detailed 10 step simulation logic

Step 1: Request Generation

- Poisson distribution has been taken for requests generation. Average requests in each hour is modelled as two parts:
  - Arrival rates found to follow polynomial distribution (wrt hours of the day) for time between 3 AM and 10 PM.

- Constant arrival rate for the rest of the day.



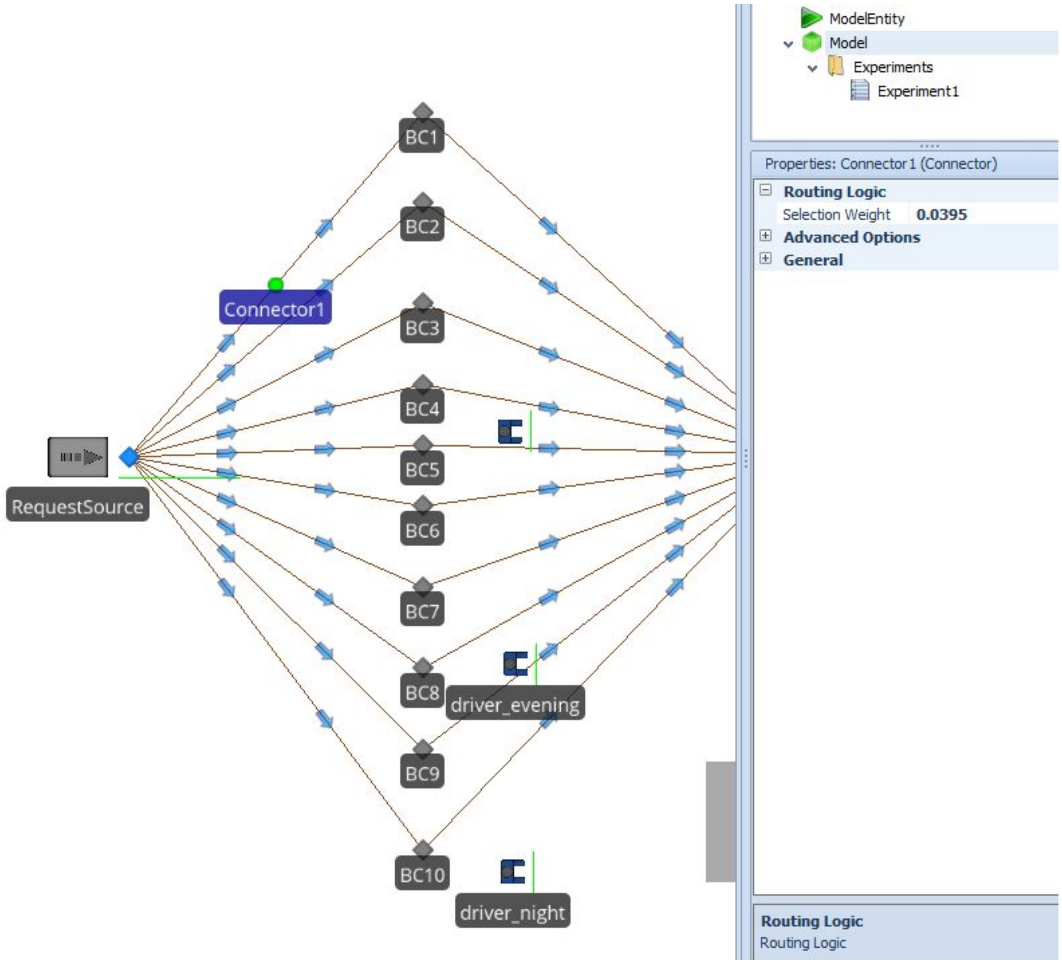
*Math.If(DateTime.Hour(TimeNow) >= 3 && DateTime.Hour(TimeNow) <= 22, Random.Exponential(60 / (-0.067 * DateTime.Hour(TimeNow)^ 2 + 1.581 * DateTime.Hour(TimeNow)- 1.289)), Random.Exponential(60 / 1.137))*

- Based on input data analysis, we understand that contribution of different business centers for requests is not constant. Following table captures % requests being generated from different business centers (and 95% CI). We have used mean values to define weights of connectors. This sums up to 1. We have tested our solution for Upper bounds of business centers.

Business Center	Mean	95% LB	95% UB
BC1	3.95%	3.50%	4.40%
BC2	8.23%	7.59%	8.86%
BC3	10.79%	10.07%	11.51%
BC4	13.55%	12.76%	14.34%
BC5	11.84%	11.09%	12.59%
BC6	5.49%	4.97%	6.02%
BC7	12.37%	11.61%	13.13%
BC8	5.79%	5.25%	6.33%

BC9	13.75%	12.95%	14.54%
BC10	14.25%	13.44%	15.06%

- Once a request is created we are assigning a business center to it based on historical distribution of contribution of different business center to overall requests.

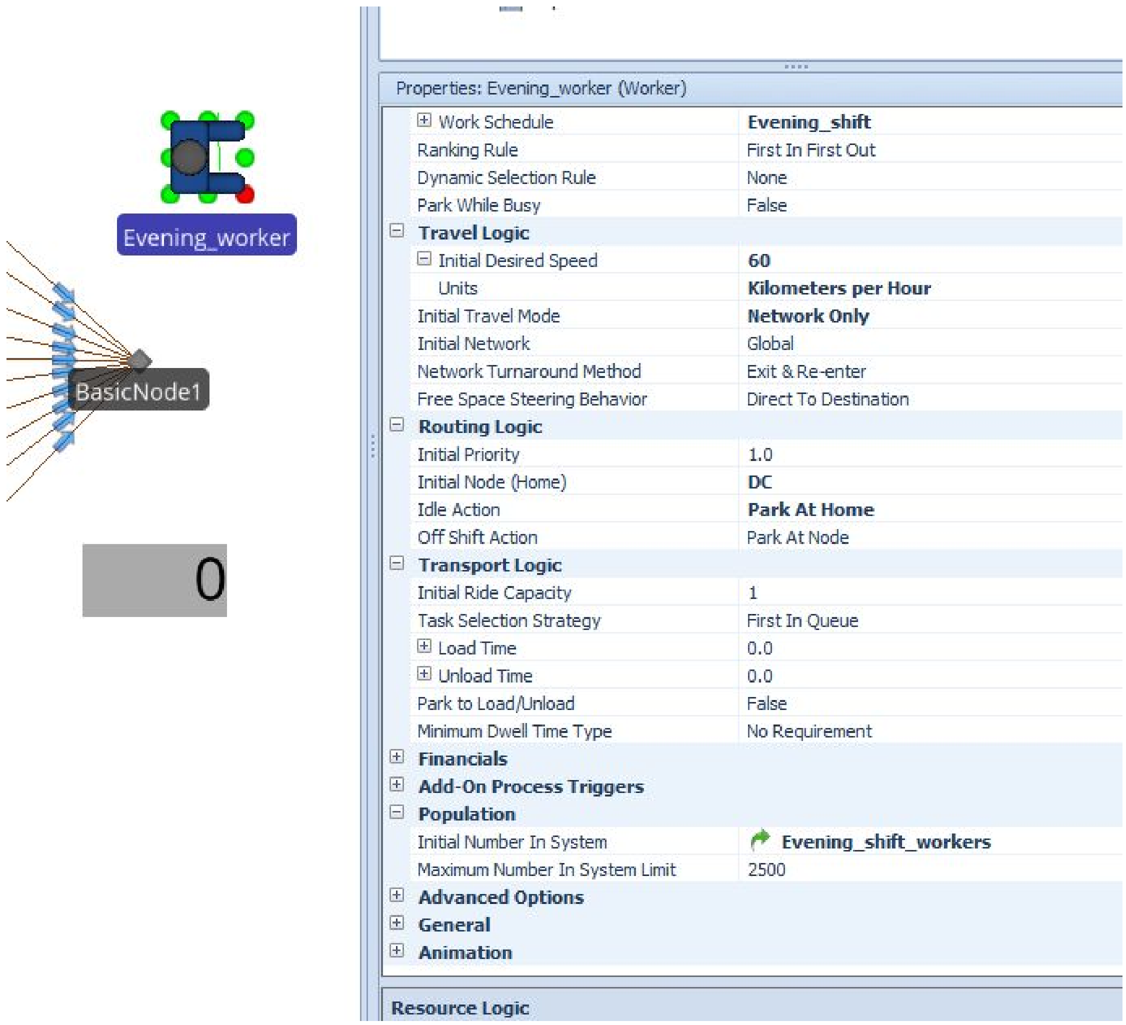


- We have used a simio add on process to move an entity to respective initial diagnosis server depending on modelentity.picture. This is done to keep model clean. Same objective could have been achieved by having 10 connectors.

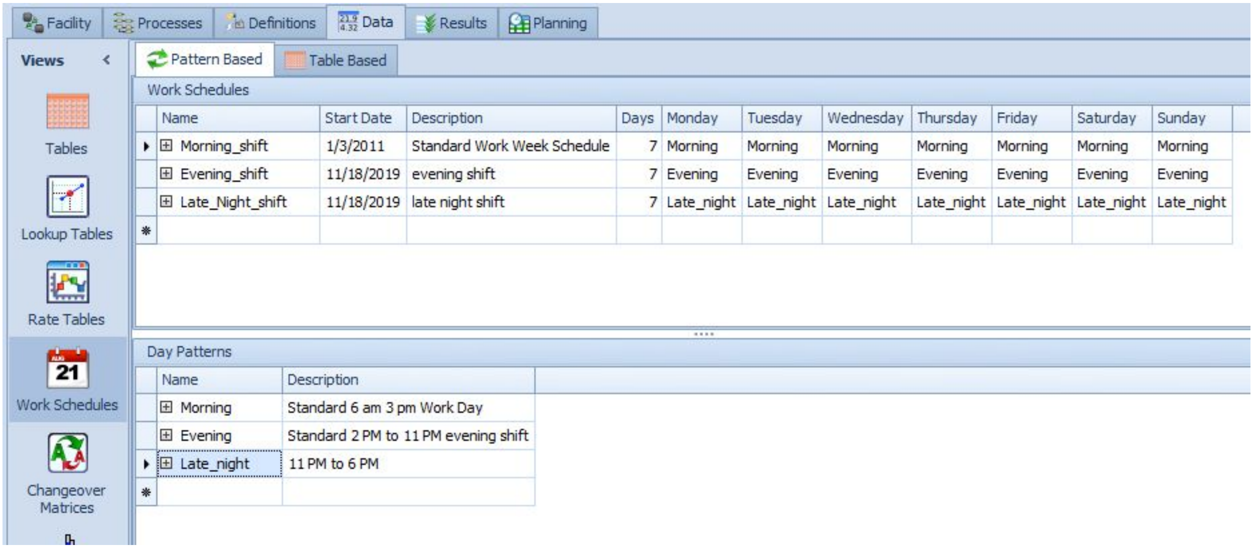
<u>Step 2: Worker object and work schedule</u>

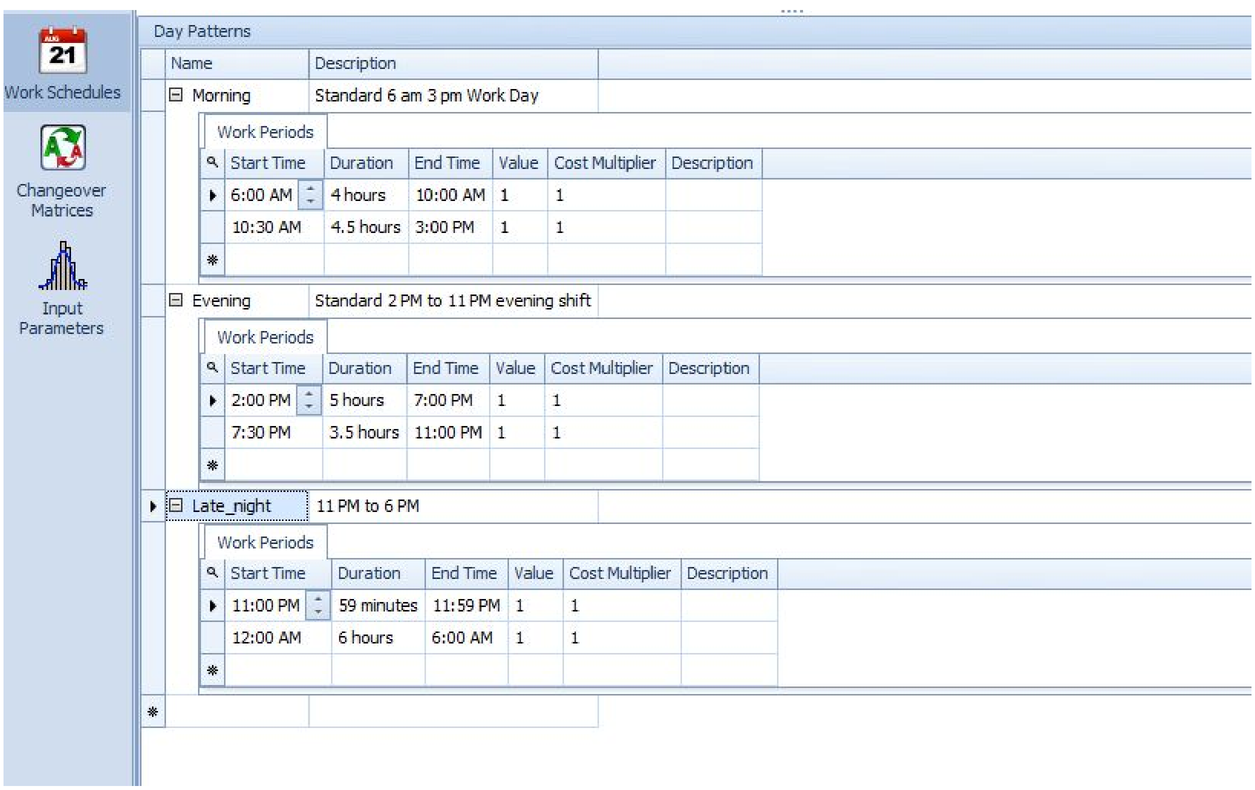
- Before processing a request on initial diagnosis server, we need one of our mechanics to reach business center physically.

- This is executed in simio, using a "worker" object. "Worker" object has following properties:
    - Work Schedule: we have defined 3 shifts as discussed below.
    - Rule for selecting among multiple tasks: We are using FIFO (First in first out).
    - Travel speed as 60 Kmph.
    - Home (initial node) as DC. This is where worker goes when shift is off.
    - When idle (on work schedule but no task available) worker remains at current node only.
    - Population defines number of instances in system (aka number of workers in this shift). This is setup as a reference variable as we iterated over this multiple times.



- Work schedule: As shown below, we have defined three shifts: morning, evening and late night. Each of these shifts have defined working hours and breaks as well.

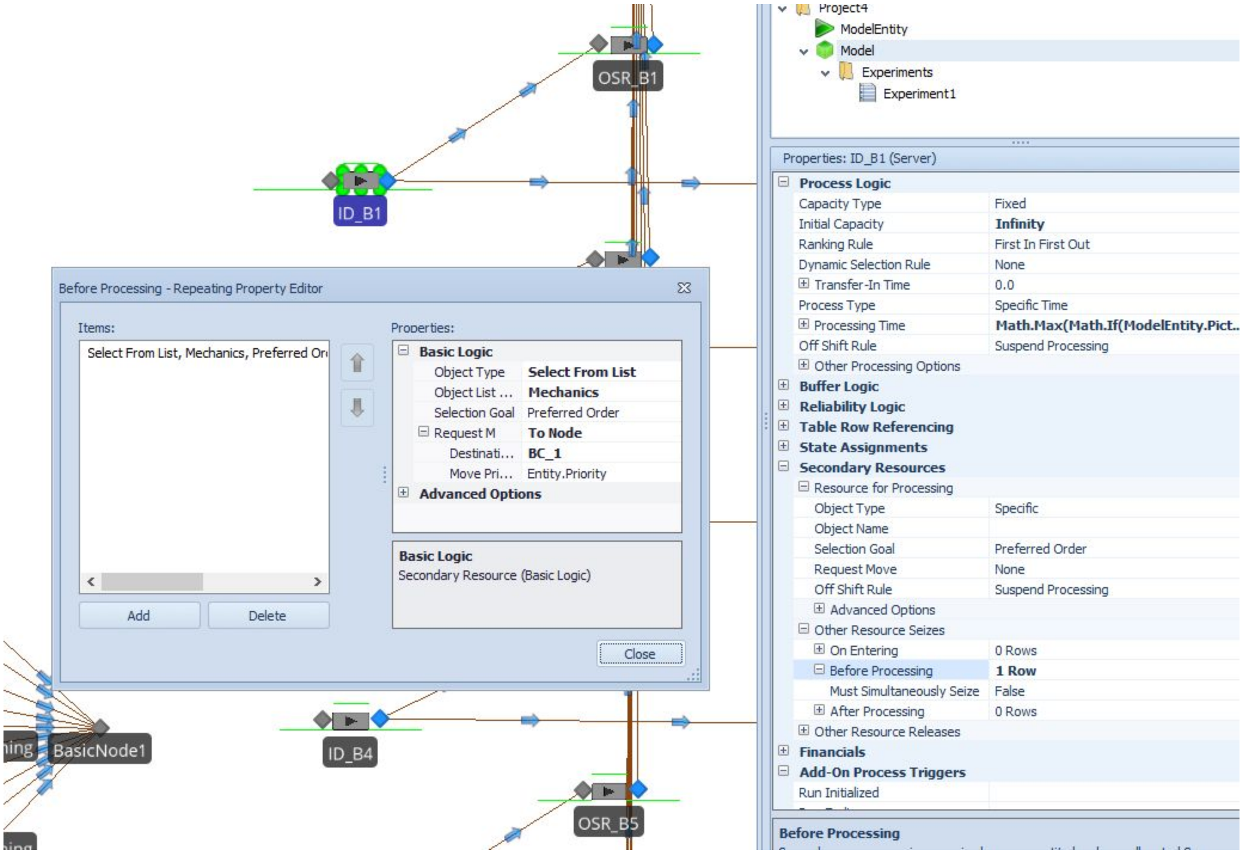




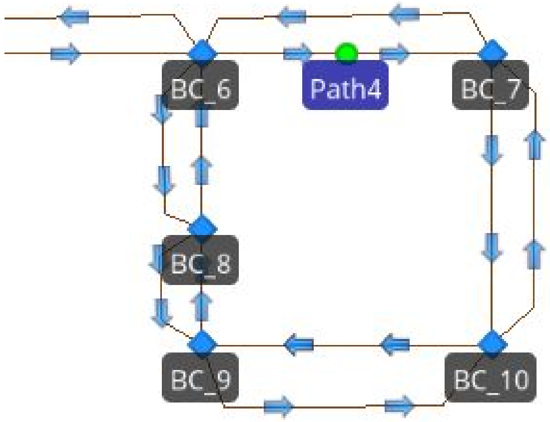
Step 3: Seizing mechanic and mechanic travels to BC

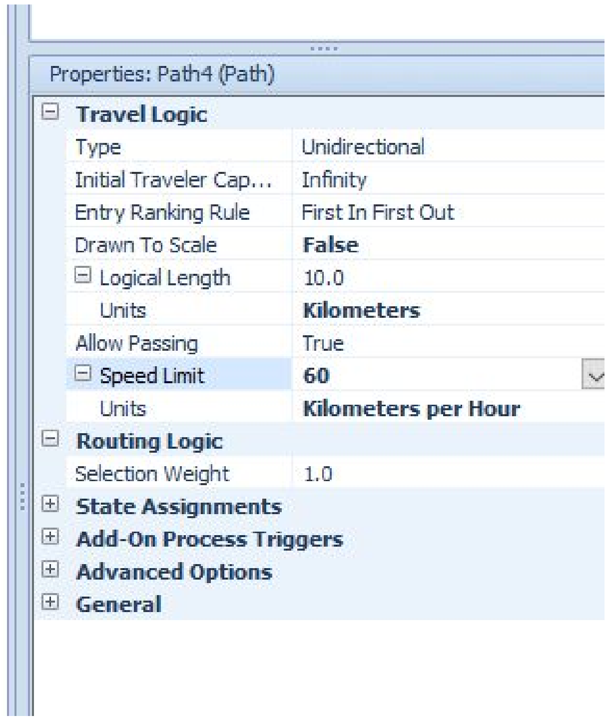
- Next we create a seize request before initial diagnosis process starts (as shown in the screenshot below):
    - Set up worker object as secondary resource required for this server.

○ Setting up request to move to respective node



- Once a worker if free and assigned to this request (as discussed above we are using FIFO logic for this - other available options are nearest, farthest, custom function).
- Note that until the worker objects reaches respective business center, requests waits in the input queue of corresponding initial diagnosis center.
- We have created a list of worker object (one for each shift) as “Mechanic”. Note that only worker who has an active shift/work schedule at that point in the simulation is considered. In case of overlapping shift, worker from any eligible shift can be assigned.
- Moving mechanic to respective business center entails some time as workers have finite travel speeds.
- As shown in the front end diagram of network, workers only move along the pre defined path. Following configurations are available while defining path:





Step 4: Initial diagnosis

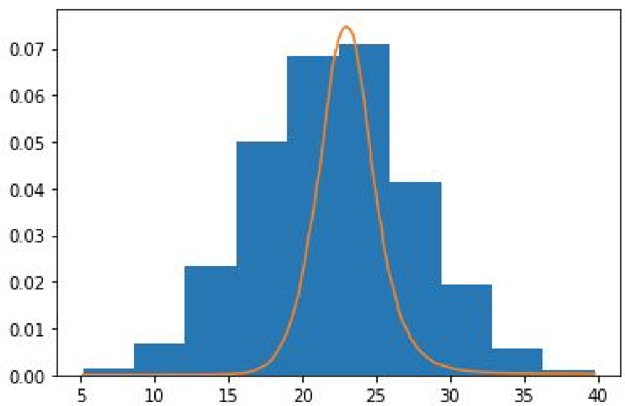
- Modelled as server object in simio.
- Initial response time is calculated as the time entity spends in the system until it clears inbound queue at this server.
- From input data, we understand that initial diagnosis follows different distribution for two different groups of business centers. The groups are

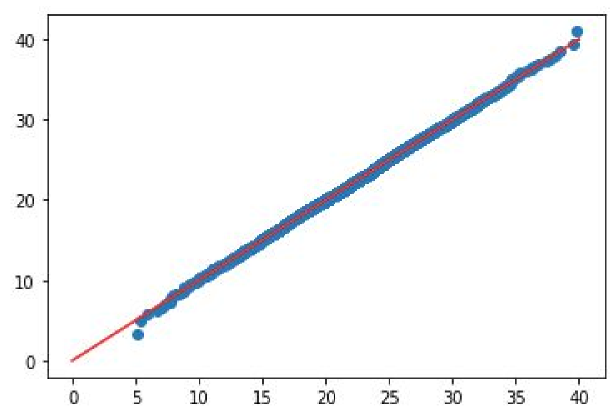
  - 1,4,5,6,7,8,10 (with mean in range of 15.96 - 16.20)
  - 2,3,9 (with mean in range of 22.02-22.18)

Business center	Average Initial diagnosis time
BC_1	15.97
BC_10	16.10
BC_2	22.17
BC_3	22.00
BC_4	16.17

BC_5	16.29
BC_6	16.15
BC_7	16.01
BC_8	16.26
BC_9	22.23

- Normal distribution fits each of these groups individually with p values being around 0.85 for each group. Q-Q plots also confirms this fit.





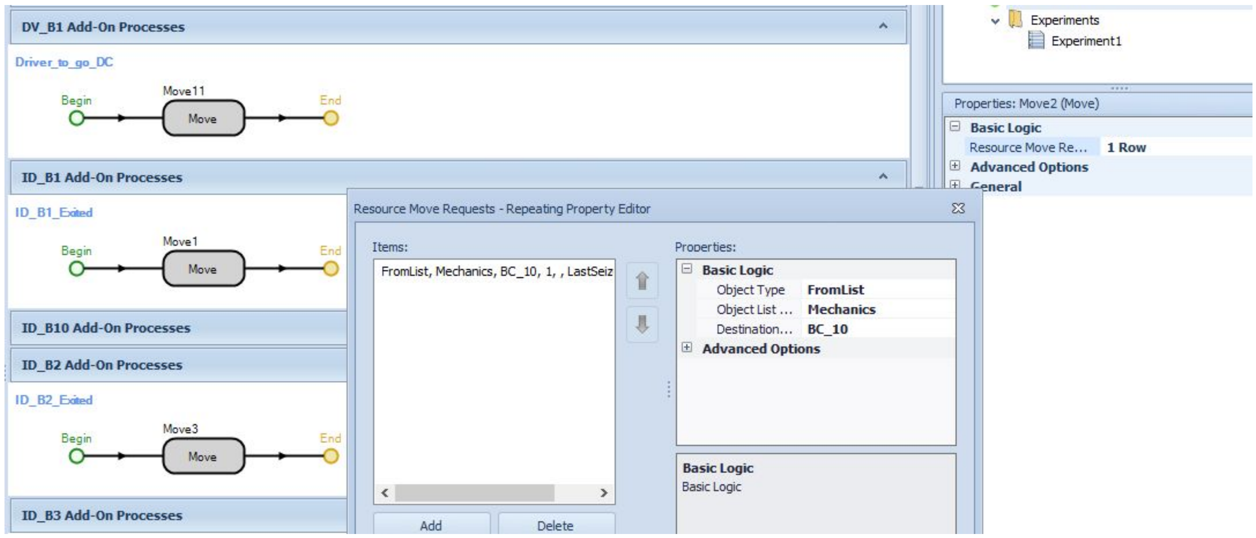
- Hence we have modelled initial diagnosis time as :
  Math.Max(Math.If(ModelEntity.Picture == 2 || ModelEntity.Picture == 3 || ModelEntity.Picture == 9, Random.Normal(16.13, 2.89), Random.Normal(22.15, 5.34)),0)

  Where "ModelEntity.Picture" object is used to identify business center source of request (as discussed in step 1.

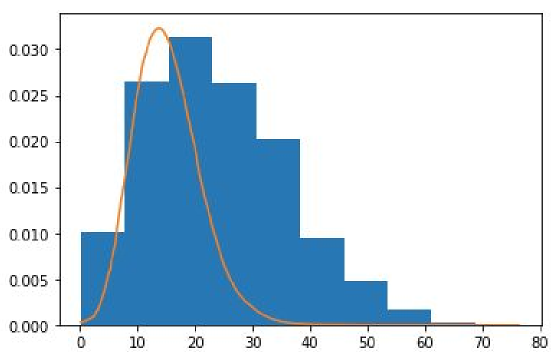
- Two outputs are possible from the initial diagnosis:
  - Onsite repair should be enough.
  - Machine needs to be swapped.

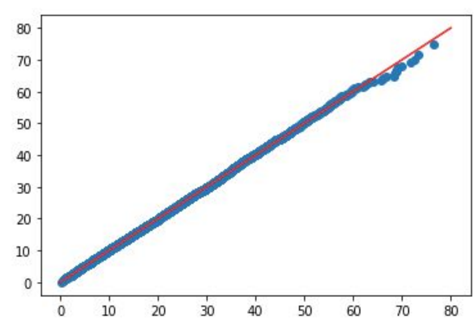
<u>Step 5: Onsite Repair Process</u>

- Modelled as server object in simio.
- In case of onsite repair is needed, we ensure that same worker remains at the business center location until onsite repair process is complete. This is achieved via add-on process. (Resource move object)



- Based on the input analysis, Onsite repair times has been modelled as beta distribution. From Q-Q plots - Beta,Raleigh and Gamma - all three looks good fit. However, going by the p-value of KS test (at 95% level, For Beta, p-value = 0.68), we have modelling on-site repair time as Beta Distribution.

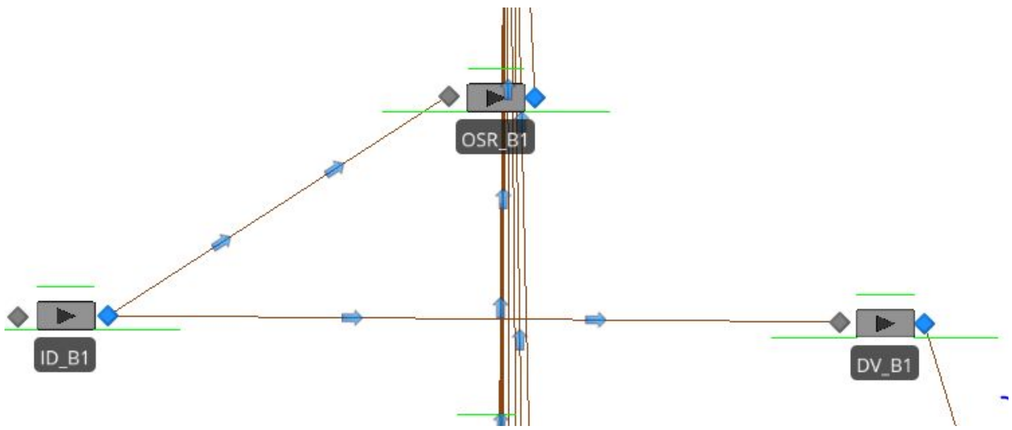




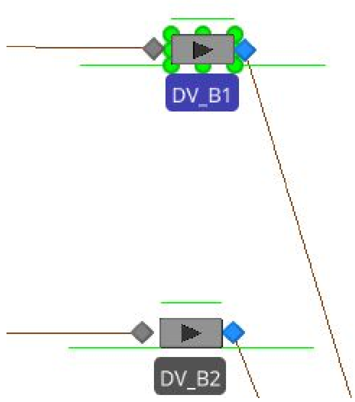
- To be precise we have modelled On site repair time as: *Math.Max(-0.4623+93.4751*Random.Beta(2.6158, 7.4606),0).* *Max function to avoid negative values for time distribution.*

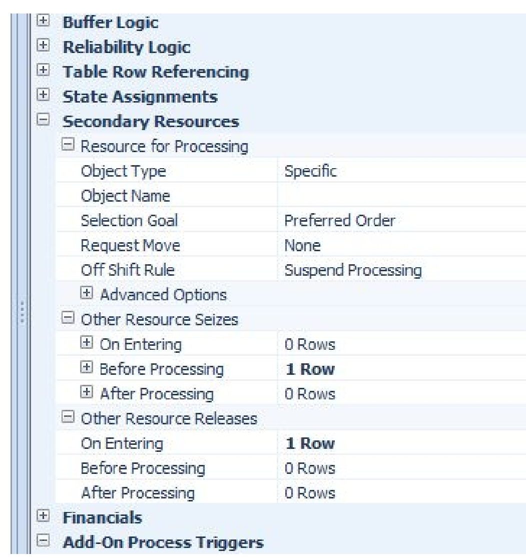
Step 6: Seizing Driver for replacement

- Based on the input analysis, we modelled 18.05% of all the requests requiring a replacement. (95% confidence interval of 17.16%, 18.94%). We have tested for these extreme values as part of sensitivity analysis.
- Request is sent to either for on site repair (step 5) or for replacement (DV server) as follow:



- Once request reaches DV server we take two actions with respect to workers:
  - We release “Mechanic” worker object as soon as entity enters this server.
  - We create a seize request for “Driver” worker object for this process can be started.
    - “Driver” worker object is similar to what we discussed in step 2.





Step 7: Driver (and Van) travels to BC

- Once “Driver” is available, it travels to respective BC location.
- Same as step 2 and 3.

Step 8: Swapping copier at BC

- Modelled as standard “server” object.
- From employee interviews we understand that min = 20, most likely = 30, max = 60 swap time at business center (all in minutes). Due to lack of more information, we have modelled swapping time at business center as: ***Random.Triangular(20,30,60)***
- Replacement time is measured as the time request entity spends in the system till this point.

Step 9: Driver travels back to DC

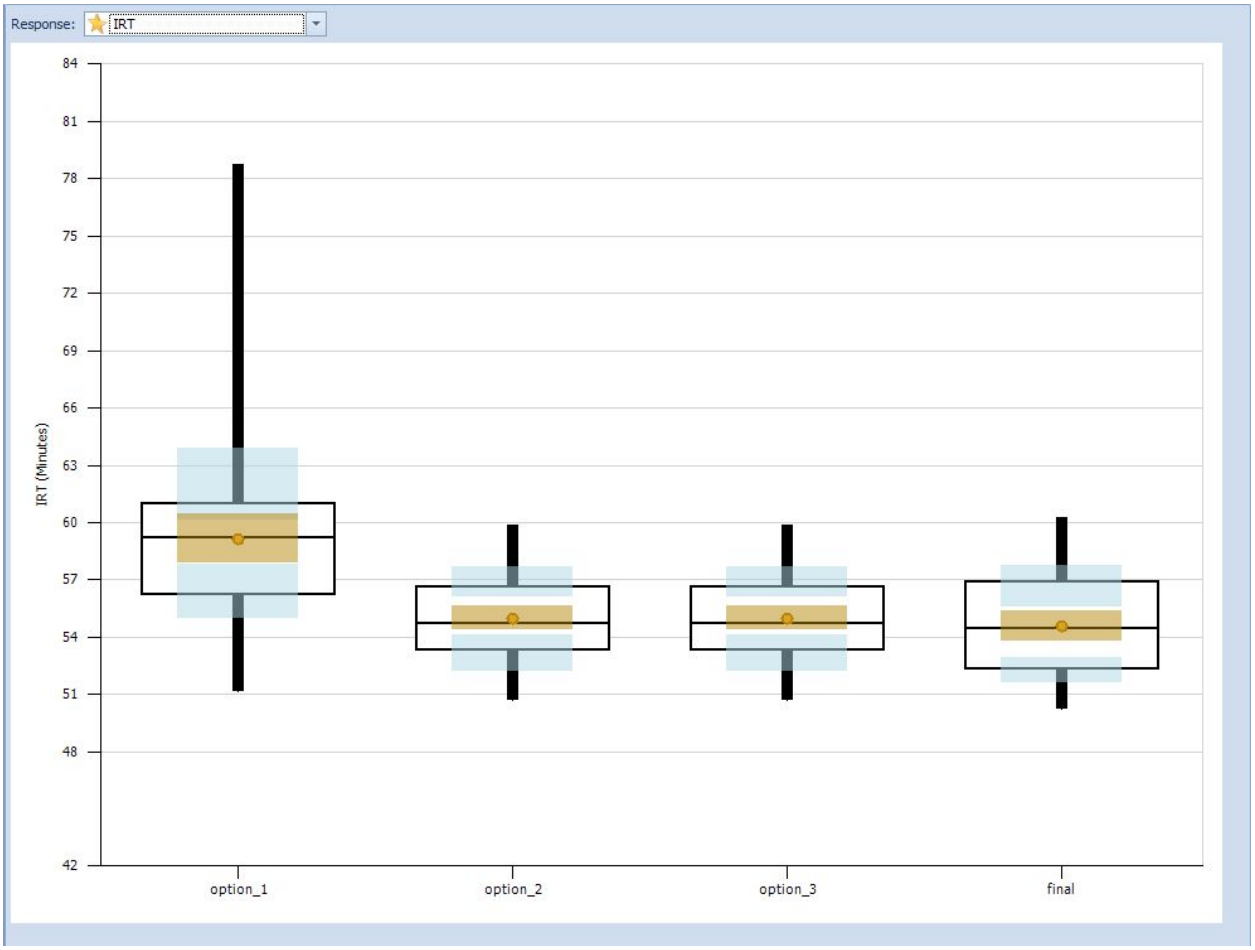
- Modelled as standard “server” object.
- “Driver” worker object now travels back to DC to replace bad copier with a new copier.
- From employee interviews we understand that min = 10, most likely = 15, max = 25 swap time at dispatch center (all in minutes). Due to lack of more information, we have modelled swapping time at dispatch center as: ***Random.Triangular(10,15,25)***

Step 10: Releasing Driver

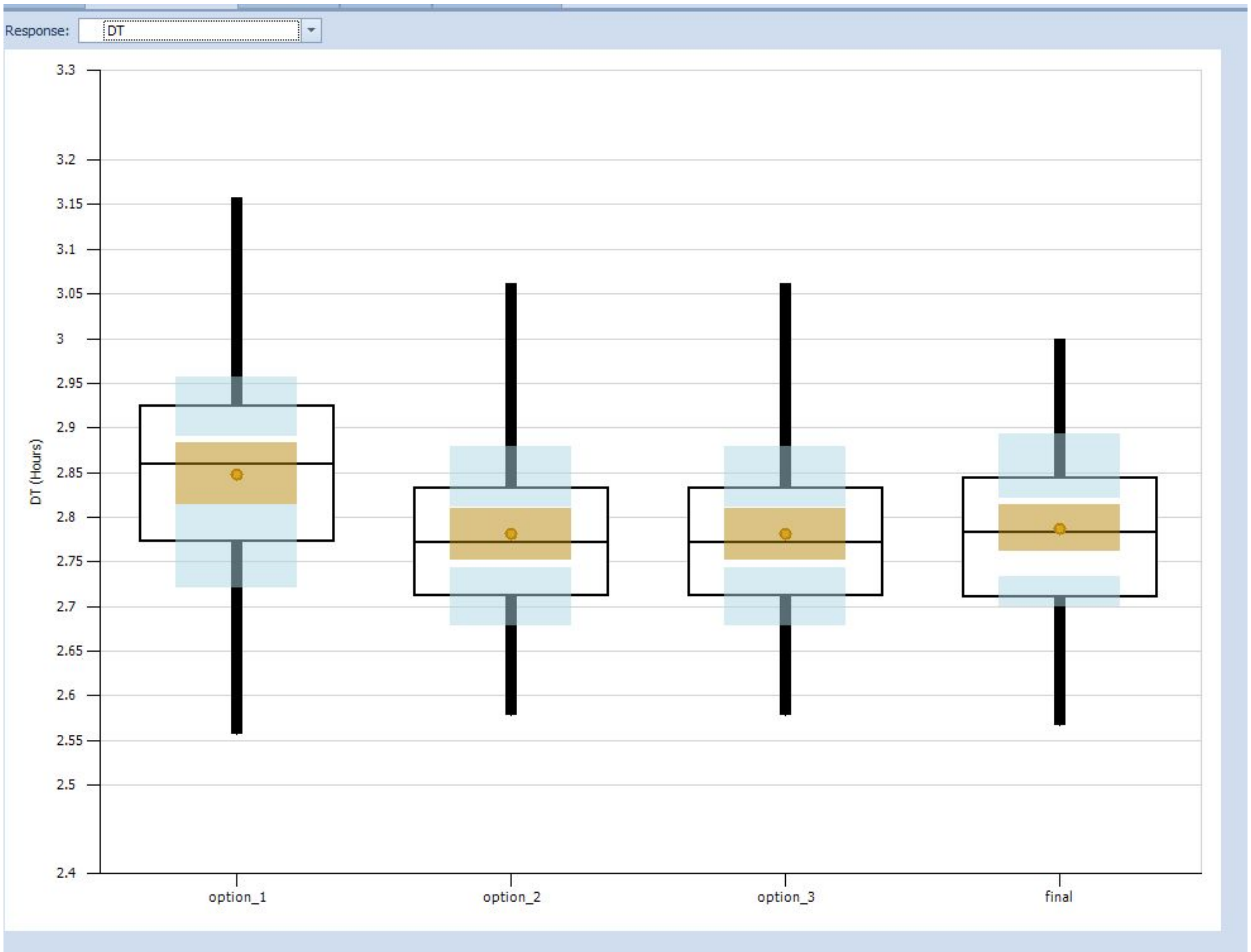
- Once replacement at the DC is done, drivers will have a new copier on its vehicle and is now released to take up any new requests.

Confidence intervals for Selected Configuration (SMORE)

Following is the SMORE graphs for Initial response times and replacement times for 4 configurations discussed in main report.

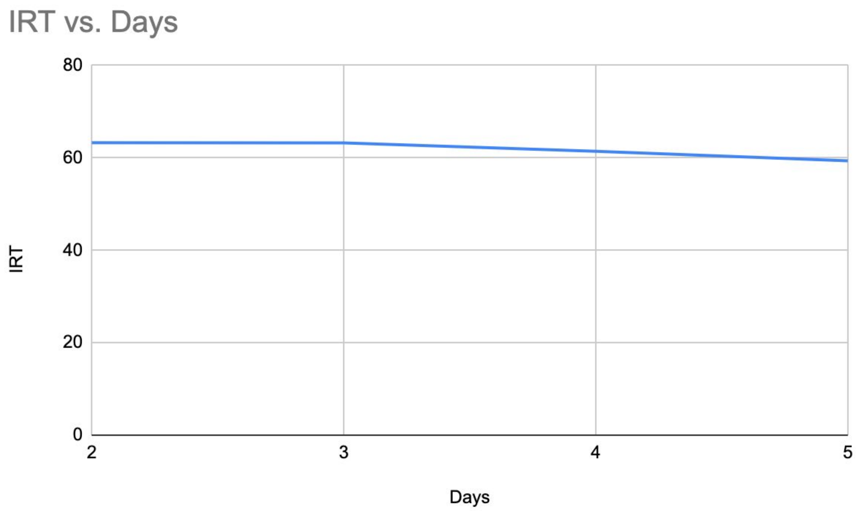


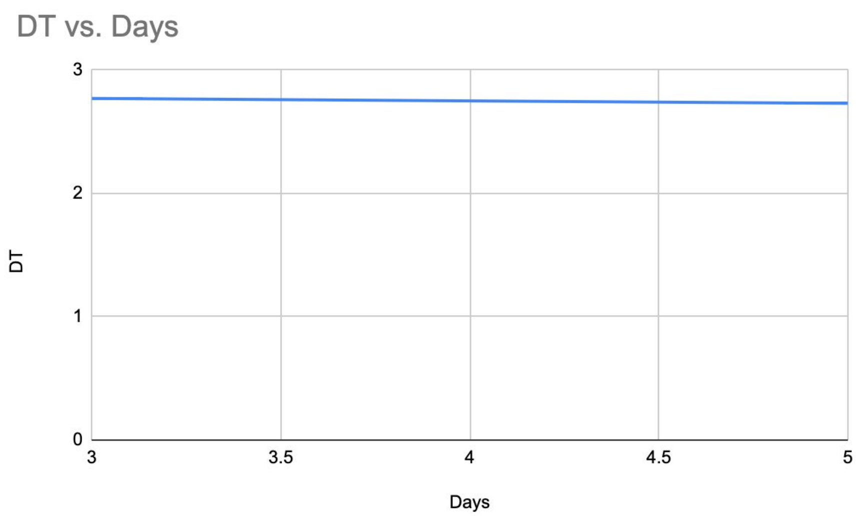
Response:
IRT
IRT (Minutes)
84
81
78
75
72
69
66
63
60
57
54
51
48
42
option_1
option_2
option_3
final



Experiment / Simulation length

- We ran each experiment for 100 iterations/runs.
- Each run, we simulated for 10 day period.
- Each run had one day warm up period.
- Output analysis shows both IRT (Initial Response Time) and DT (Replacement time) have been stable in this range.

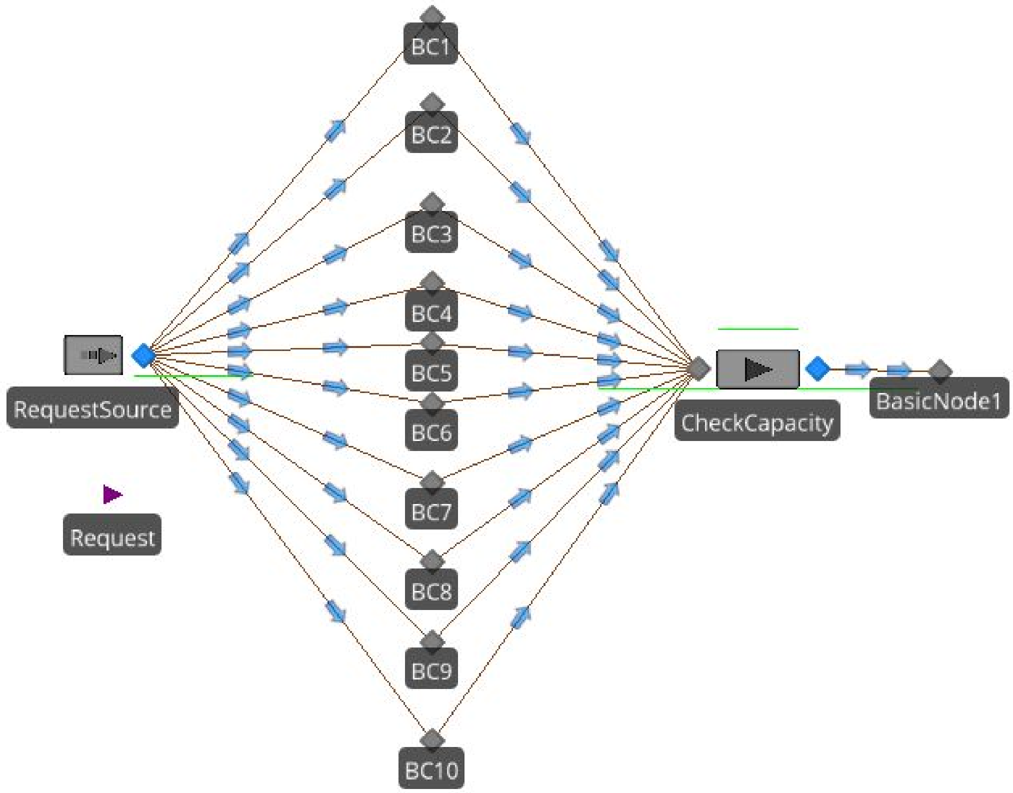


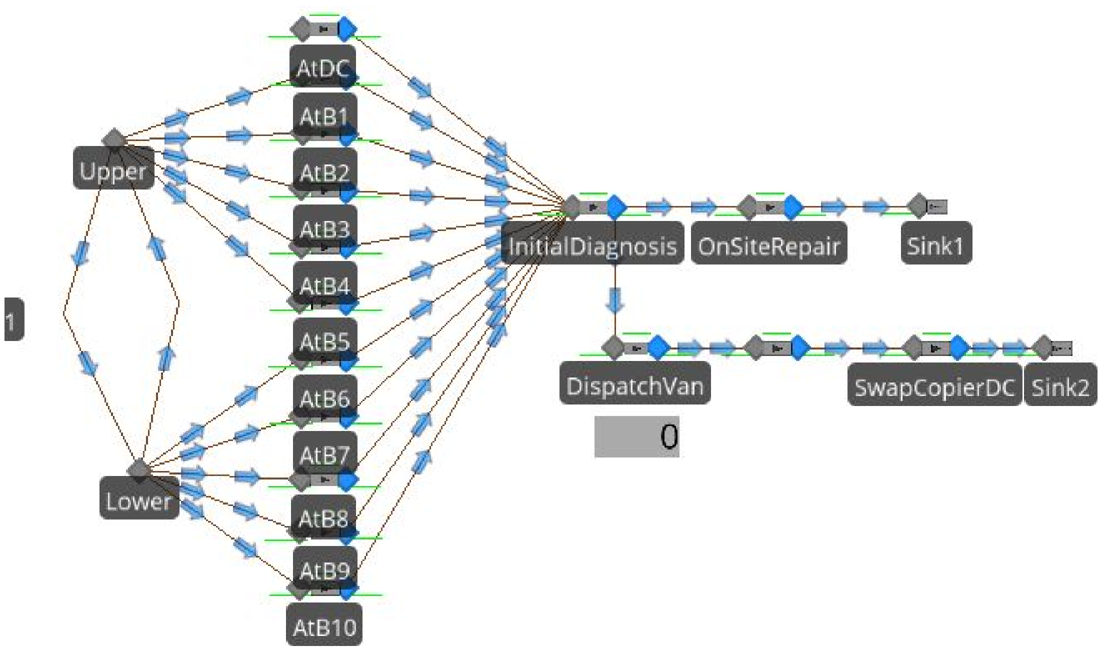


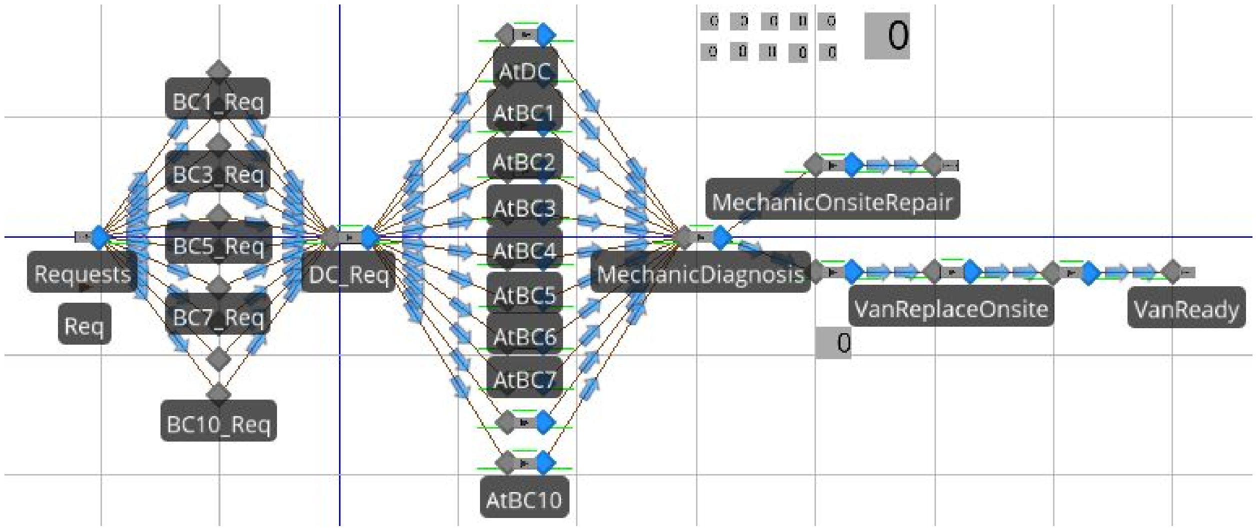
Details of Model verification

Level 1: Converging two independent models

Two similar models were built with different logic as shown below. The logic of the model is fairly similar to the one described above. Second model looks like the following:


BC1
BC2
BC3
BC4
BC5
BC6
BC7
BC8
BC9
BC10
RequestSource
Request
CheckCapacity
BasicNode1

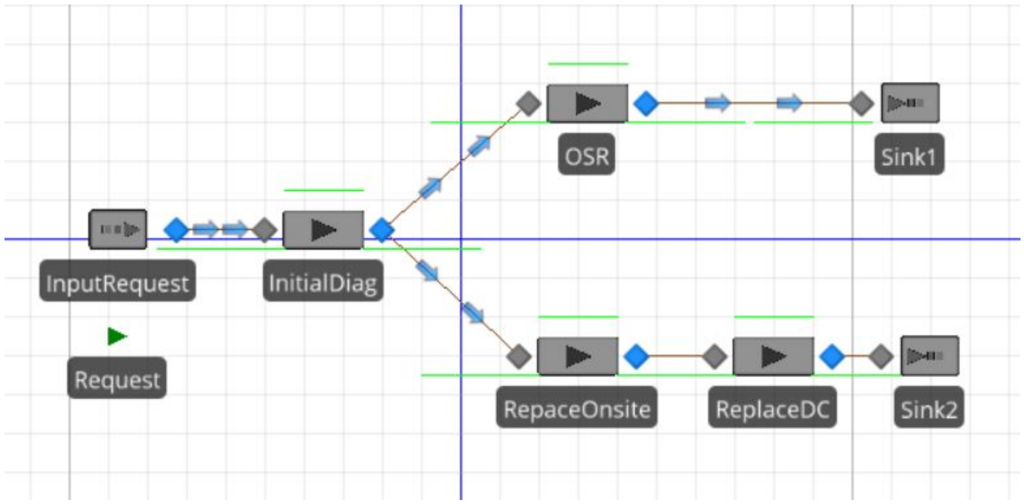

AtDC
AtB1
AtB2
AtB3
AtB4
AtB5
AtB6
AtB7
AtB8
AtB9
AtB10
Upper
Lower
1
InitialDiagnosis
OnSiteRepair
Sink1
DispatchVan
SwapCopierDC
Sink2
0



The two models are different in the following ways:

- In the second model, we vary the capacities (quantity of requests a server can process) of different servers in real time to model worker availability.
- In the second model, we use explicit data tables to provide travel time and speeds among different entities - rather than defining a network as in first model.
- Second model assumes workers to be available throughout the day - which is essentially the same as having the same number of workers across all shifts.
- In Second model workers are restricted to move within a cluster of nearby business centers, where as in the first model there is no such restriction.
- We chose first model as its more intuitive, allows different number of peoples across shifts, quicker experiment and a front end.

<u>Level 2: Comparing output metrics with an approximate system</u>



We developed a simple “Average” model combining all business centers into one center. This average version help us to perform a sanity check of the system. Key attributes of this average model are:

- We take an average time of travelling among different combinations of business centers, between business centers and distribution center.
- Here, the path between the Input Request and Initial diagnosis is time path with travel time of approximately 45 minutes. This is an estimate of the travel times to the various BCs.
- The weights are 70% for the ones with normal distribution having a mean of 16.13 and 30% for the ones with normal distribution having a mean of 22 in it’s “servicing times”.
- The initial diagnosis service time is a weighted average of the means of the business centers with differing service rates.
- A time path is also added between the Initial Diagnosis and OnSite replacement and between OSR and Replacement at DC. This is to ensure that we capture the travel times between business centers and the time taken to travel between DC and the Replacement.
- Swapping time, On site repair times and replacement probability is the same for all business center anyways.

Level 3: Directional tests

Many directional test cases were used to understand the behaviour of the system and to really understand how the IRT and DT changes with the parameters.

Case 1: Increase the number of vans and worker and check the responses.

# Vans	#Worker	IRT	DT
4	9	61.13	2.74
5	10	51.241	2.47
6	11	46.52	2.371

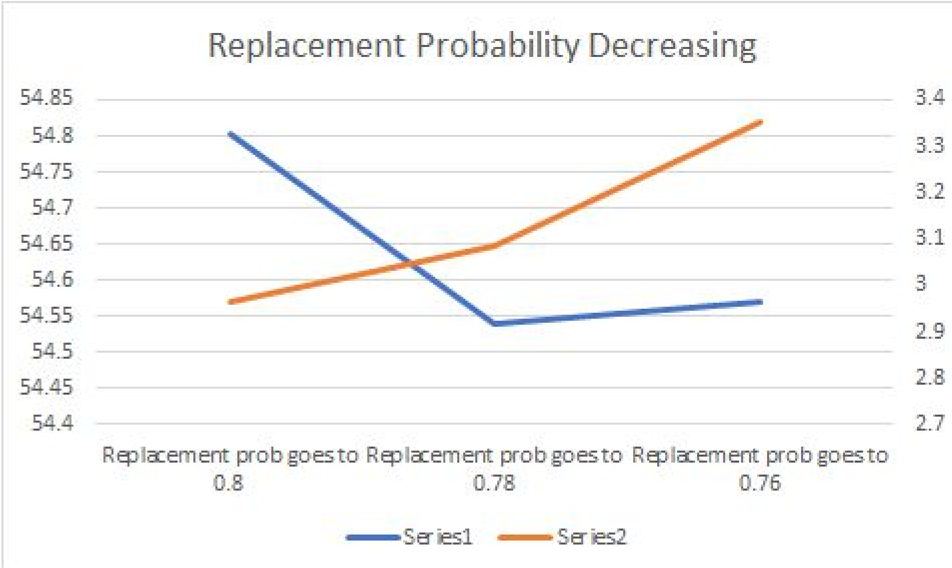
Case 2: Increase Speed

Morning, Evening	Night	IRT	DT
40	100	116	4.02
40	20	138	4.69
100	40	35.06	2.01

Case 3: Create a traffic in Quadrilaterals of Business centers 2,3 and 6,7,8,9,10 by limiting speeds on the connecting roads to 30 kmph.

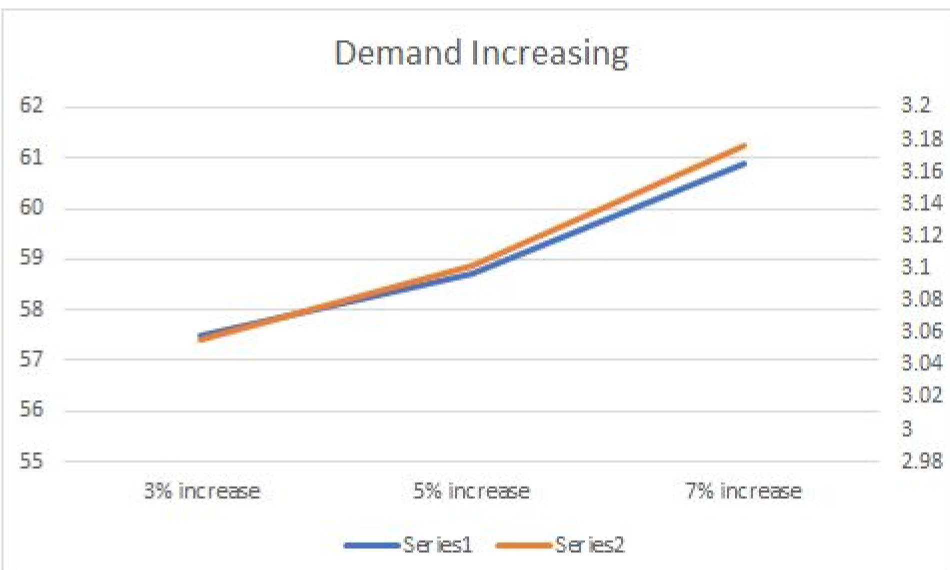
# Vans	#Worker	IRT	DT
4	9	103	3.73

Case 4: If the On Site Repair Probability dropped to zero



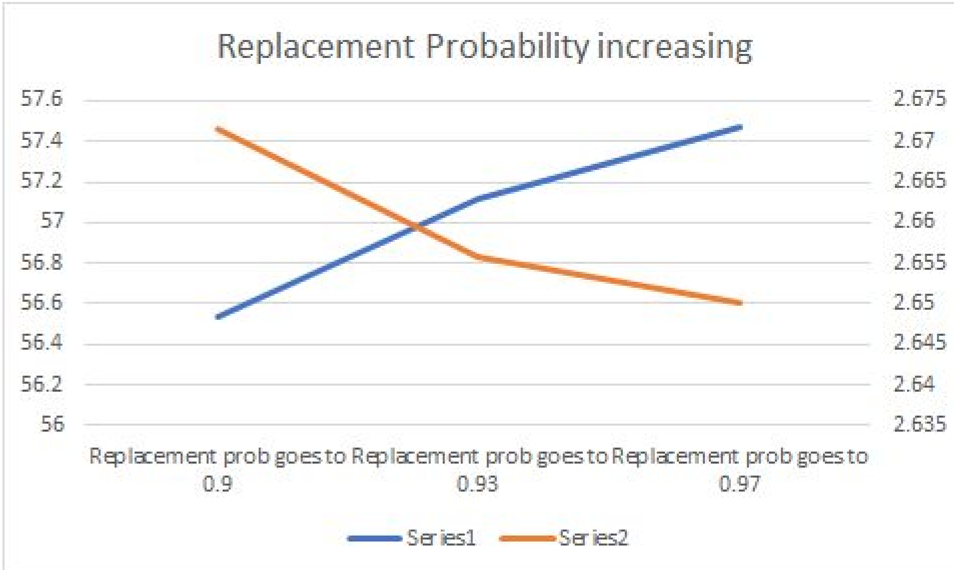
Series 1 is replacement time and series 2 is initial response time.

Case 5: Increasing demand



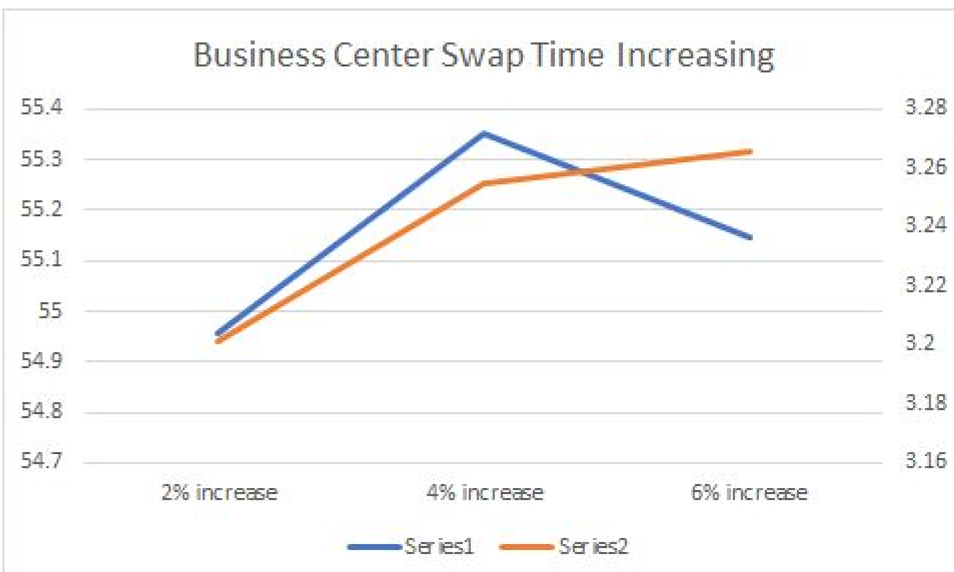
Series 1 is replacement time and series 2 is initial response time.

Case 6: If the Probability of Requiring Replacement dropped to zero



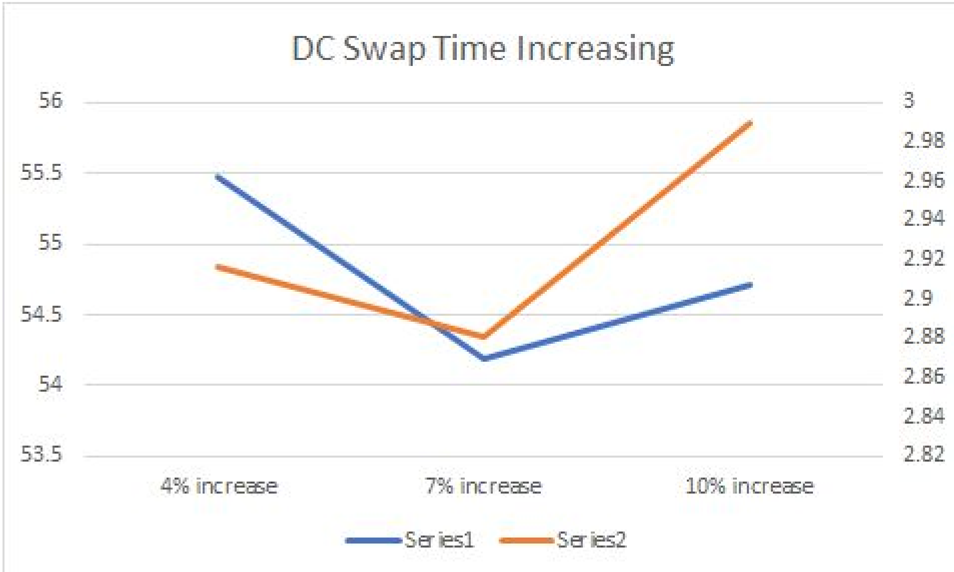
Series 1 is replacement time and series 2 is initial response time.

Case 7: Increasing Business center swapping times



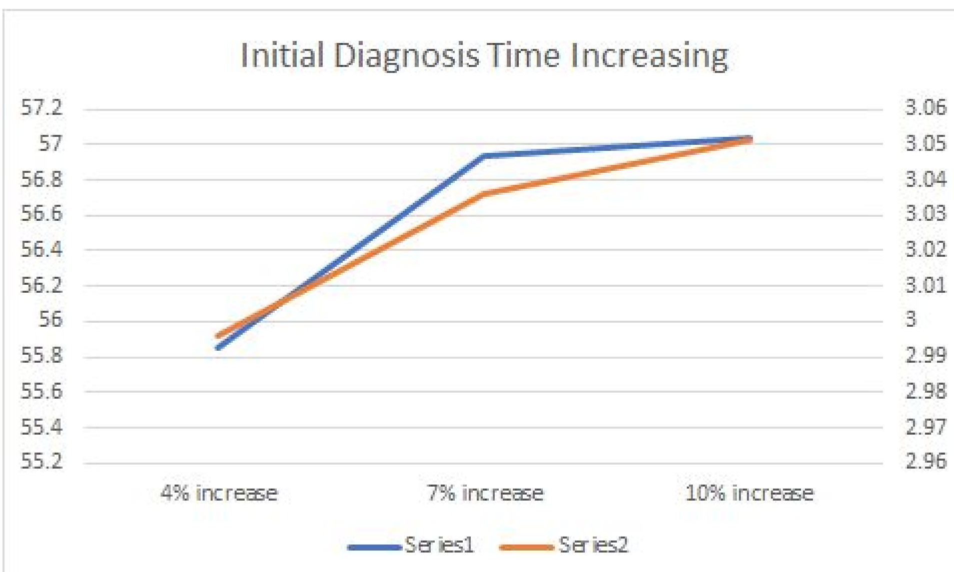
Series 1 is replacement time and series 2 is initial response time.

Case 8: When we increase the time taken to swap at dispatch center



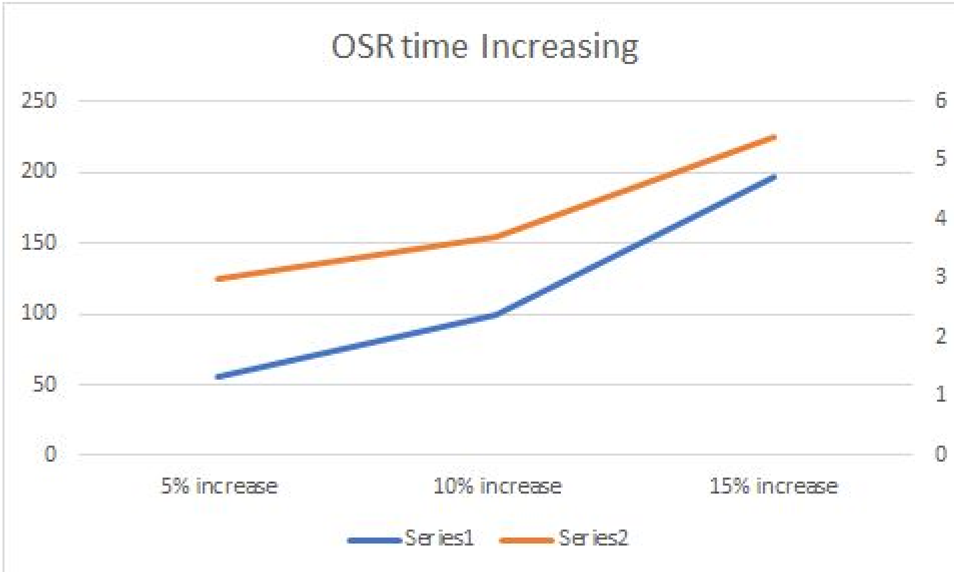
Series 1 is replacement time and series 2 is initial response time.

Case 9: Increasing the Initial Diagnosis time arbitrarily



Series 1 is replacement time and series 2 is initial response time.

Case 10: Increasing the On Site Repair Time



Series 1 is replacement time and series 2 is initial response time.