ECE 4320 - Fall 2020 Course Project:
Operating the Georgia Power Grid During a Pandemic Situation

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1 Executive Summary

The purpose of this project is to develop a set of instructions to maintain, repair, and improve the operation of a simulated model of the Georgia power system during the outbreak of a pandemic. What makes such an outbreak so problematic on a grid is the need to quarantine maintenance and repair crews upon infection, which delays when lines get repaired, should they fail. The goal here is to develop methods of security to foresee incoming failures for different transmission lines based on importance, plan contingencies around these expected failures, and develop a schedule to properly allocate maintenance and repair crews based on likelihood of infection and how many are already quarantined. The end of each simulation produces a score, which is essentially the total cost needed to run the system for that simulation. Naturally, it needs to be minimized. After conducting copious amounts of simulations and collecting plentiful data, we found that the most cost-effective way to use the model involves using:

1. A contingency of security where at least one line is expected to fail on each turn.
2. A repair schedule where the amount of crews sent out to one line is based on the percentage of total load that the failed lines shed.
3. A maintenance schedule that sends out crews based on the likelihood of an infection occurring.

2 Introduction

After the unprecedented arrival of the COVID-19 pandemic this year, now more than ever, are we incentivized to create contingencies to mitigate future pandemics and similar crises. This is largely due to the fact that state and local governments were required to shut down parts of the economy, for a certain portion of time, to prevent the disease from spreading further, which lead to major fluctuations in energy demand. This too can adversely affect the degree of successful maintenance done for power grids as well. Three focal points of importance, whose behaviors would most likely indicate how the disease has affected the nation, are the public health sectors, commercial sectors, and social distancing mandates.

The impact of the shutdowns perpetuated by the pandemic was first made evident in New York City when night time lighting decreased by 40% between February and April [1]. Beginning around mid-March, a large increase in stay-at-home orders appeared to have caused a steep drop in electrical consumption. According to *Figure 1*, the weekly average of new cases dropped significantly after April 14th in New York, but the rate of reduction for electricity consumption continued to increase and peaked at 15.6% on June 2nd. Very similar patterns were observed in Philadelphia, Kansas City, Los Angeles, Chicago, and Boston. These findings may prove a weak sensitivity of electrical consumption to rising case numbers in certain cities [2].

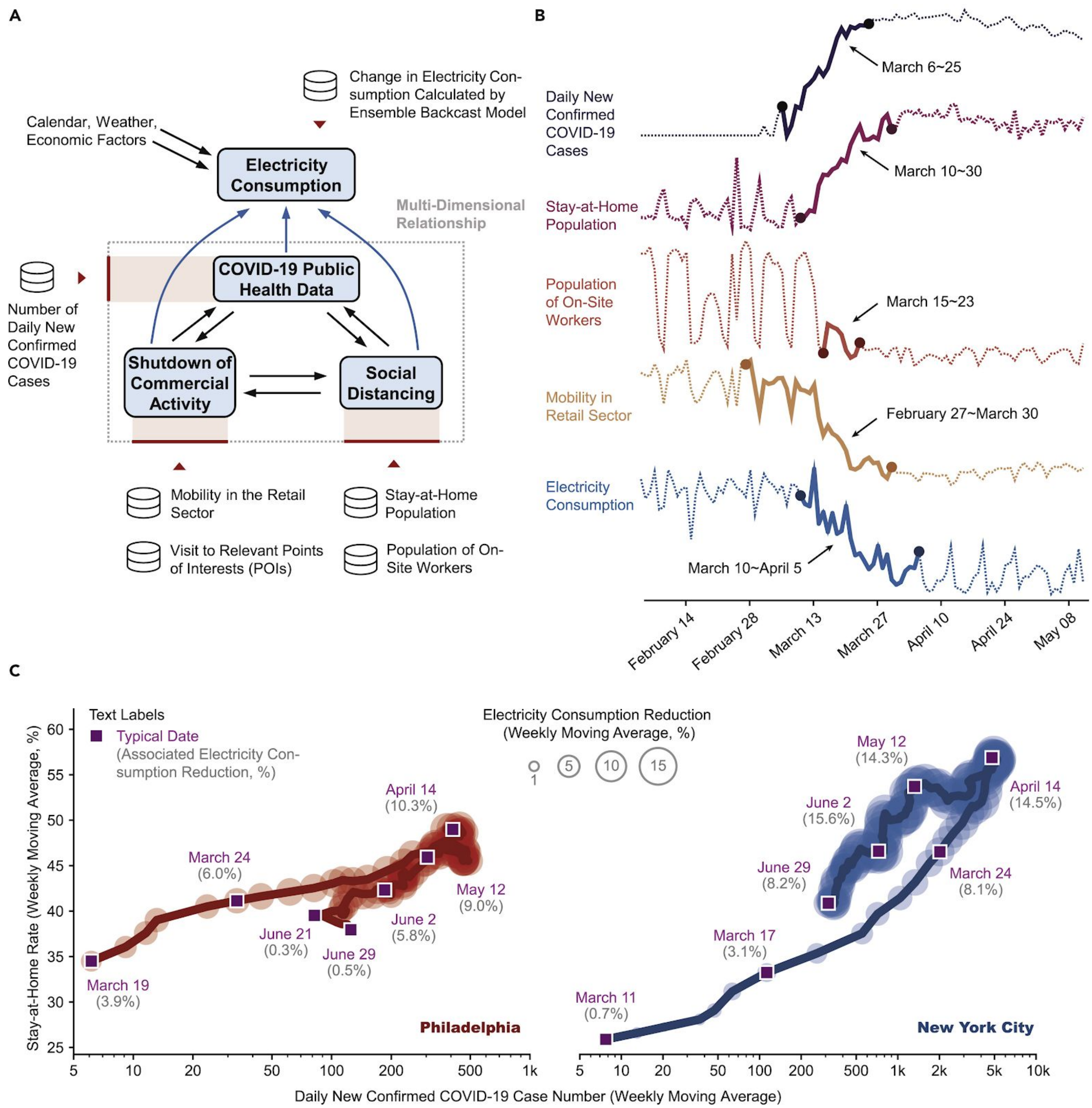

Figure 1: Factors influencing New York energy production due to COVID-19 [2].

What appears to have the biggest impact on power grids is the withholding of operation in the commercial and retail sectors. For New York, Philadelphia, and Houston, a 1% decrease in retail mobility in conjunction with a 1% increase in COVID cases in steady state, caused a decrease in electricity consumption by 0.25%, 0.48%, and 0.78% respectively. Despite the easing of mandates and a reopening in May, many states still experienced power demand lower than that of 2019. Almost every region that was affected by the pandemic experienced a reduction in energy demand within the range of 10% to 30% [3]. Although a decrease in demand has helped alleviate some harm done to our environment, the pandemic has greatly increased the risks of workforce disruptions, supply chain disruptions, and increased risks of breaches in cybersecurity due to more teleworking employees [4]. This system model will focus primarily on how to mitigate any adverse effects caused by such disruptions and how to efficiently prevent them altogether.

3 Pandemic Simulation Model

The Pandemic Simulation Model is a heavily simplified model of the State of Georgia's power transmission system. It features 20 busses, 6 generators, and 30 transmission lines, shown in *Figure 2*, and is modeled using a DC power flow approximation. Throughout the simulation, each time cycle is composed of three segments: night, day, and evening, with night having lower levels of demand and evenings having the highest. Each bus's load demands are arbitrarily modulated using gaussian random variables 'opts.Pmu' and 'opts.Psigma', which represent mean value and standard deviation respectively. Their maximum load thresholds cannot be surpassed, otherwise load must be shed at a certain cost per MWh with these costs being consistent over all time periods. Generator cost coefficients are also consistent over different time periods. Furthermore, ramp rates and startup/shutdown time requirements are not taken into account.

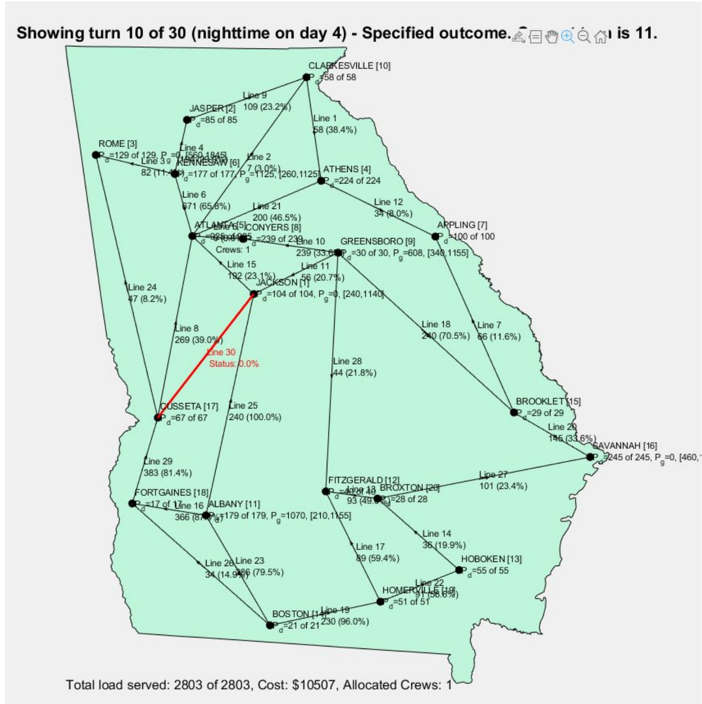

Figure 2 - Georgia Power Grid Pandemic Simulation Model [5]

At each line, an exogenous failure probability is assigned, with this probability increasing by a set factor during each new time period. The program randomly determines which lines fail based on these probabilities. Lines on the periphery of ones that fail are at risk of overloading which in turn causes a cascade of failures. An overloaded line fails with a probability that is proportional to the amount of overload, and has a zero chance of failing if the load is at or below its threshold. New line flows are also calculated based on the ones that fail.

To reduce the exogenous failure probability of a line, the user can assign crews to lines that have not yet failed to perform maintenance, but only for the next turn. This value however, cannot be reduced below a set minimum for this probability. If a line has already failed, a crew can be assigned to it in order to facilitate repairs on the next turn. A line is considered to have failed if its status is below 1. The higher the value for maintenance effectiveness, the better they can increase this value for a single turn, and the faster a line is repaired (status is returned to or beyond 1). The more crews assigned to a failed line, the less turns it needs to be repaired. It is important to note that a value of likelihood for infecting a crew working on a line is established for the simulation as well. If just one crew is infected, all other crews at that same line are quarantined and can no longer be used for the remainder of the simulation. Additionally, because this harms a crew member's quality of life, infected crews have a multiplicative increase on the final score of the simulation.

Two scripts are provided to help solve DC power flow problems and security constrained unit commitment problems for each turn. A third script is also provided that enables the user to run through all 30 turns of the simulation with a predetermined set of conditions to follow. The first solver, 'rundcpf_with_islands', computes the power flows at each line using the given load and generator outputs. The second script, 'rundcscuc' takes in two inputs: a power system dataset and a matrix denoting a set of contingencies for a given row. Each row represents a line, and a column represents a desired contingency of failure, which is selected with a value of 1. The solution then gives generator setpoints and load demands that minimize cost without having to violate the constraints selected in the second input of the function. The last script, 'benchmark_approach', takes in a power system model, number of available crews, the current turn, and number of the last turn, as inputs. It then provides the generator output, load demand, and crew allocation matrix for the current turn [5].

4 Experimental Setup

The experiment started by running the simulation through the ‘GUI-Based Interface’ a few times to obtain a feel for how the system typically operated under different constraints and crew allocations. With a baseline set for the system's operation established, the approach was switched over to the ‘Function-Based Interface’ to automate the simulation to run multiple times with set parameters unattended. This was required to remove the effect of randomness in the power-grid’s loads, line failures and crew quarantine.

Data collection started by using a provided simulation function, ‘benchmark_approach.m’, as a baseline to determine the best constraints for the simulation and to compare the changes made in the crew allocation again to see if there was improvement. The benchmark approach was used to run 150 times for each of three different types of constraints, ‘N-0’, ‘N-1’, and ‘N-2’ security, inputted into the DC security-constrained unit-commitment solver. The results of the simulations, as shown in *Table 1*, show that ‘N-1’ security had the lowest score, while ‘N-0’ was cheaper and ‘N-2’ resulted in simulations reaching a gridlock where too many lines failed with no crews left to repair them. Due to the lower score, and additional system protection over N-0 constraints, N-1 security was chosen for all simulations going forward.

Table 1: Benchmark Approach - DC SU-UC Constraints

N-0 Security	**N-1 Security**	**N-2 Security**
Average Score over 150 Simulations	Average Score over 150 Simulations	Average Score over 2 Simulations
58.8560E+6	35.8293E+6	1.0038E+9

With the DC SU-UC constraints chosen, the next simulation parameter to alter was crew assignment. As noted in Section 3, quarantined crews have a multiplicative factor on the overall final score, making it paramount to reduce possible crew exposure. The first attempt to remove possible infection was to remove all crew maintenance on the system, but keeping the repair crew rules from the benchmark approach. Seen in *Table 2*, the overall score skyrocketed when the system was run without maintenance. The lack of maintenance caused lines to constantly fail, resulting in more crews being sent out for repairs. The additional crew repairs neglected the savings of having less crews out for maintenance while adding on additional load shed to the system. Furthermore, this change resulted in having N-1 also experience a rare situation where the system was stuck in a total failure without repair crews. It is clear that a different approach to crew allocation needed to be taken, as with the current infection rate maintenance would be required for a low-cost operation.

Table 2: Benchmark Approach - No Maintenance Crews

N-0 Security	**N-1 Security**	**N-2 Security**
Average Score over 150 Simulations	Average Score over 79 Simulations	Average Score over 8 Simulations
163.0402E+6	102.5567E+6	818.4898E+6

With line maintenance proven to be essential to low-cost operation, this experiment required a method to determine how to allocate crews to have less group exposure while shedding minimal load. Thus, a line analysis was run to determine how much load a failure of each line would shed in each of the 30 turns based on the ‘N-1’ Security Constrained Unit Commitment algorithm. Due to the randomness of each run of the simulation, this analysis was run five times and had the results averaged for a more accurate representation. The resulting matrix, shown in *Appendix 1*, could be used to determine the ranking of lines to repair in each turn based on the amount of load they shed upon failure. This information was added to the simulation's dataset to allow for its use in future functions.

The ranking of each line's load shedding upon failure can now be used to create a more conserative crew repair plan than the benchmark approach. The line analysis is loaded into the function and is called when a line fails. Upon line failure, the function determines what percentage the line normally sheds upon failure against the total simulation load for that turn. This percentage is what determines if one, two or three crews are sent out for the repair, as opposed to sending many crews to repair the line as fast as possible. Different percentages were determined and tested to find an appropriate balance for the default crew infection rate. If the average load shed was below the first percentage of total load, one crew is sent. If it is between the two percentages, two crews, and if it is above the second precenatage three crews are sent as it is an important line. *Table 3* shows that for the default infection rate of 5%, the best repair approach was allocating the crews based on 1% and 5% of the total load. Additionally the scores showed that this approach was a better pandemic instruction set than the benchmark approach.

Table 3: Load Shed Repair Approach

0.5% - 1%	**1% - 5%**	**5% - 10%**
Average Score over 50 Simulations	Average Score over 100 Simulations	Average Score over 100 Simulations
25.6161E+06	22.0678E+06	25.7942E+06

While 1% and 5% total load was the most cost-effective for the default infection rate, we wanted to see how changing the rate would affect this result. Seen in *Table 4*, the best percentages changed when the infection rate was doubled to 10%. With the higher infection rate an even more conservative crew allocation was required, showing that these percentages need to be determined for each pandemic. Additionally, the higher an infection rate, the better the approach becomes as compared to the benchmark.

Table 4: Load Shed Repair Approach - Double Infection Rate

Benchmark Approach	**1% - 5%**	**5% - 10%**
Average Score over 50 Simulations	Average Score over 100 Simulations	Average Score over 100 Simulations
130.0997E+06	76.3683E+06	58.7355E+06

Lastly, we experimented with creating a reduced maintenance schedule that scales with the amount of crews quarantined. The new function kept crews maintaining lines with the highest probability of failure but would send out fewer maintenance crews as the total number of crews was reduced. This was done to try to both reduce the crew quarantine cost and conserve crews for future repairs. The repair plan was set to the [1%, 5%] configuration as it was the most effective for normal infection rate to ensure any increase or decrease in score was due to the received maintenance crew allocation.

The results of the maintenance plan are shown in *Table 5 and Table 6*. For the normal crew infection rate, it was shown that the reduced maintenance had an inverse effect on the final score. This showed that with a low enough infection rate it is beneficial to have more maintenance than shedding loads in possible future line failures. However, when tested for double infection rate the maintenance plan produced a lower score than the [1%, 5%] repair plan on it's own. While the reduced maintenance plan can be beneficial, it requires a higher infection rate to come into play than the simulation's default.

Table 5: Load Shed Repair (1% - 5%) & Maintenance Approach

>10 Crew - Send 50% >5 Crew - Send 25%	**>10 Crew - Send 25% >5 Crew - Send 10%**	**>10 Crew - Send 100% >7 Crew - Send 50% >4 Crew - Send 0%**
Average Score over 100 Simulations	Average Score over 50 Simulations	Average Score over 100 Simulations
29.4068E+06	36.0431E+06	56.5071E+06

Table 6: Load Shed Repair (1% - 5%) & Maintenance Approach - Double Infection Rate

>10 Crew - Send 50% >5 Crew - Send 25%	**>10 Crew - Send 25% >5 Crew - Send 10%**	**>10 Crew - Send 100% >7 Crew - Send 50% >4 Crew - Send 0%**
Average Score over 50 Simulations	Average Score over 50 Simulations	Average Score over 50 Simulations
94.4059E+06	67.4479E+06	78.2114E+06

5 Results and Recommendations

Firstly, it was apparent to us that implementing anything except for ‘N-1’ security, was less than optimal. Having no security in place at all was certainly a route that we could have taken, but it proved to be less cost-efficient as lines would fail with nothing in place to mitigate the effects. On the other hand, implementing ‘N-2’ security commonly led to situations where the entire system would shut down. This was due to needing more repair crews than we could possibly provide, so it was unanimous in fully avoiding using such a method. However this could just be due to a weird quirk in the simulation model. Furthermore, we felt that ‘N-0’ security was not safe, especially if we planned to play with crew allocation and other parameters in future simulations. For this, we recommend using strictly ‘N-1’ security.

Another pair of parameters we agreed to consistently oversee and utilize were repair and maintenance. As stated before, crew quarantine has a multiplicative increase on the final score of a simulation, and all crews working on the same line will be quarantined if one is infected. This leads to a balancing game of risk of losing multiple crews and speed of a line’s repair. To address this the amount of crews sent for each repair was weighted by the amount of average load shed that a line’s failure creates in that turn compared to the total load. The optimal range we determined was [1%, 5%] when assuming the default infection rate (5%). However, doubling the infection rate to 10% optimized a range of [5%, 10%], showing that the percentages of total load will need to be determined for each infection rate.

With repair allocations accounted for, a new maintenance plan was proposed and tested. Smaller groups of crews proved to produce a lower score, so it was determined to try and reduce the amount of crews performing maintenance each turn. Maintenance crews were allocated to lines with the highest probability of failure, and the amount of crews sent out decreased as crews were quarantined. For the default infection rate (5%), it was found to be most effective to constantly send all available crews to perform maintenance for each turn. However, when the infection rate was doubled (10%), the score benefited from reducing maintenance as crews were lost.

In conclusion, we recommend always using ‘N-1’ security as well as a schedule that varies the amount of crews delegated to a line repair depending on its average load shed. Delivery of maintenance is heavily dependent on the infection rate, with lower rates allowing for all remaining crews to perform as needed, and higher rates requiring less crews than available to be allocated.

6 Limitations and Future Works

The main limitation of this analysis was the time that the group had to learn and play around with the theoretical power grid system. While simulations were run through the GUI to get a feel of how the system operates and reacts to conditions, this cannot replace the intuition and experience of a power engineer who has worked with the real system for years. Having experience with the system for an extended period of time would give better insight to the most important lines in a system, what some previous major failures are, and having experience with the actual line crews to better allocate them. Additionally this experience would be useful to know if part of the simulation was not functioning as the real system would. Seeing a discrepancy between how you know the system would act and how the simulation acts would allow errors to be ironed out and lead to a more accurate model.

The second limitation of this approach was the simplicity of the simulation model. As described in Section 3, the pandemic simulation only accounts for DC power flow and line failures. While the recommendations given in this report should serve as a useful guide, there could be unaccounted scenarios that cannot be addressed until the robustness and complexity of this system is expanded upon. Some examples are the repair and maintenance guides, as they are only accounting for line failures, so there might need to be a more aggressive maintenance and repair approach with the possibility of generator and bus failures.

Future work to do with this project would be to develop an algorithm that can take the infection rate of a pandemic and automatically adjust the load shed percentages for repair allocation and how many crews to send depending on the remaining amount. The project used a method of assuming values and simulating them to find the lowest point. An algorithm would be able to pinpoint the exact lowest point and would be able to automatically change the parameters if the infection rate was to vary throughout the simulation. We believe that a Riemann Sum solver could be added and modified to find the lowest operating point.

7 Conclusion

As shown during the COVID-19 pandemic, the need for a plan of action for operating an essential utility during situations of this nature is critical. With the possibility of crews being quarantined, a crew allocation plan for maintenance and line repair needs to be calculated based on a transmission line's probability to fail and its importance to the system. This can prove to be a rigorous task, but having these methods in place holds plenty of potential to save expenses and maintain livelihood in the event of future pandemics. Fortunately, there is plenty of room for improvement with a model like this and others alike, which only entails better system preparedness and competence, should similar future events ever occur again.

8 Works Cited

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[2] G. Ruan, D. Wu, X. Zheng, H. Zhong, C. Kang, M. A. Dahleh, S. Sivaranjani, L. Xie, “A Cross-Domain Approach to Analyzing the Short-Run Impact of COVID-19 on the US Electricity Sector,” *Joule*, vol. 4, no. 11, Sept. 21, 2020. [Online serial]. Available: https://www.sciencedirect.com/science/article/pii/S2542435120303986. [Accessed Dec 1, 2020].

[3] R. Madurai Elavarasan, G. M. Shafiullah, K. Raju, V. Mudgal, M. T. Arif, T. Jamal, S. Subramanian, V. S. Sriraja Balaguru, K. S. Reddy, and U. Subramaniam, “COVID-19: Impact analysis and recommendations for power sector operation,” *NCBI*, 31-Aug-2020. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7458120/. [Accessed: 01-Dec-2020].

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[5] D. Molzahn, “ECE 4320 Fall 2020 Course Project: Power System Pandemic,” Oct. 23, 2020. [Online]. [Accessed Nov. 27, 2020].

9 Appendix

	Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Turn 6	Turn 7	Turn 8	Turn 9	Turn 10	Turn 11	Turn 12	Turn 13	Turn 14	Turn 15
	Night	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night	Day	Evening
Line 1	0	15	153	93	209	0	123	0	93	209	0	123	49	67	0
Line 2	58	184	351	161	333	187	298	170	161	333	72	298	1	72	325
Line 3	94	229	416	241	423	247	315	227	241	423	137	315	42	97	359
Line 4	0	33	144	103	223	0	142	0	103	223	0	142	61	80	0
Line 5	183	318	446	310	465	339	382	284	310	465	173	382	74	128	443
Line 6	171	363	526	325	450	388	394	349	325	450	249	394	79	116	480
Line 7	0	27	165	99	254	0	161	2	99	254	0	161	0	49	26
Line 8	85	272	439	221	393	297	317	272	221	393	151	317	20	99	435
Line 9	127	294	473	284	429	311	370	276	284	429	192	370	58	115	442
Line 10	0	25	162	102	228	0	148	0	102	228	0	148	61	82	0
Line 11	90	223	355	226	390	220	324	190	226	390	92	324	22	75	348
Line 12	102	276	434	255	410	283	301	272	255	410	167	301	21	79	412
Line 13	0	17	169	95	237	0	124	0	95	237	0	124	108	77	0
Line 14	32	130	285	145	324	60	237	62	145	324	20	237	0	72	116
Line 15	95	273	426	247	433	320	321	298	247	433	181	321	40	109	469
Line 16	0	21	157	97	203	0	157	0	97	203	0	157	61	59	0
Line 17	0	42	158	113	238	0	149	0	113	238	0	149	66	56	6
Line 18	2	63	188	121	232	0	197	0	121	232	0	197	0	63	14
Line 19	0	17	145	93	204	0	118	0	93	204	0	118	108	75	0
Line 20	0	32	160	109	252	0	159	0	109	252	0	159	53	76	0
Line 21	0	55	185	120	242	0	199	14	120	242	0	199	68	80	41
Line 22	0	18	149	96	249	0	129	0	96	249	0	129	62	66	0
Line 23	96	212	359	225	395	198	301	169	225	395	75	301	25	92	303
Line 24	105	224	354	235	429	196	325	169	235	429	104	325	43	105	304
Line 25	0	48	179	115	235	0	175	0	115	235	0	175	0	56	20
Line 26	118	303	461	257	409	338	353	297	257	409	173	353	31	92	449
Line 27	260	486	660	423	565	533	481	491	423	565	374	481	156	171	639
Line 28	0	32	161	103	226	0	141	3	103	226	0	141	0	54	32
Line 29	144	365	519	302	446	414	370	374	302	446	232	370	55	99	529
Line 30	176	380	555	338	465	440	365	383	338	465	243	365	60	107	539
TOTALS	1,940	4,979	9,334	5,656	9,992	4,770	7,577	4,305	5,656	9,992	2,637	7,577	1,425	2,569	6,731

	Turn 16	Turn 17	Turn 18	Turn 19	Turn 20	Turn 21	Turn 22	Turn 23	Turn 24	Turn 25	Turn 26	Turn 27	Turn 28	Turn 29	Turn 30	TOTALS	
	Night	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night	Day	Evening		
Line 1	0	0	0	0	243	123	67	0	153	0	0	243	0	0	0	1,964	Line 1
Line 2	17	2	34	30	448	325	72	17	351	3	2	448	7	96	57	4,914	Line 2
Line 3	84	31	68	81	598	363	97	67	416	64	30	598	39	160	122	6,624	Line 3
Line 4	0	0	0	0	244	142	80	0	144	0	0	244	0	0	0	2,110	Line 4
Line 5	121	48	127	138	518	453	128	107	446	99	43	518	83	178	153	7,864	Line 5
Line 6	138	45	145	128	474	464	116	113	526	102	41	474	75	261	203	8,365	Line 6
Line 7	0	0	0	0	298	161	49	0	165	0	0	298	0	0	0	2,271	Line 7
Line 8	64	14	66	69	549	381	99	53	439	30	13	549	31	180	129	6,598	Line 8
Line 9	106	36	116	102	606	425	115	87	473	75	33	606	52	198	159	7,646	Line 9
Line 10	0	0	0	0	254	148	82	0	162	0	0	254	0	0	0	2,185	Line 10
Line 11	45	16	53	65	570	350	75	33	355	36	14	570	25	114	76	5,893	Line 11
Line 12	100	9	57	69	593	385	79	69	434	64	7	593	21	192	152	6,802	Line 12
Line 13	0	0	0	0	222	124	77	0	169	0	0	222	0	0	0	2,096	Line 13
Line 14	0	0	8	31	460	240	72	0	285	0	0	460	5	31	16	3,796	Line 14
Line 15	97	33	71	84	496	392	109	78	426	70	33	496	40	206	156	7,001	Line 15
Line 16	0	0	0	0	265	157	59	0	157	0	0	265	0	0	0	2,113	Line 16
Line 17	0	0	0	0	278	149	56	0	158	0	0	278	0	0	0	2,247	Line 17
Line 18	0	0	0	4	298	197	63	0	188	0	0	298	0	0	0	2,478	Line 18
Line 19	0	0	0	0	235	118	75	0	145	0	0	235	0	0	0	1,980	Line 19
Line 20	0	0	0	0	248	159	76	0	160	0	0	248	0	0	0	2,253	Line 20
Line 21	0	0	0	0	264	199	80	0	185	0	0	264	0	0	0	2,557	Line 21
Line 22	0	0	0	0	277	129	66	0	149	0	0	277	0	0	0	2,142	Line 22
Line 23	50	13	42	68	556	323	92	37	359	38	12	556	24	88	66	5,698	Line 23
Line 24	72	33	68	84	476	348	105	58	354	61	29	476	43	116	90	5,999	Line 24
Line 25	0	0	0	0	292	175	56	0	179	0	0	292	0	0	0	2,346	Line 25
Line 26	71	12	93	60	501	418	92	60	461	34	12	501	23	190	137	6,968	Line 26
Line 27	247	106	237	191	756	581	171	200	660	198	100	756	134	402	326	11,774	Line 27
Line 28	0	0	0	0	271	141	54	0	161	0	0	271	0	0	0	2,123	Line 28
Line 29	124	22	118	99	700	467	99	97	519	85	19	700	51	257	194	8,518	Line 29
Line 30	130	47	121	119	699	453	107	111	555	99	44	699	64	274	202	8,943	Line 30
TOTALS	1,466	466	1,424	1,421	12,691	8,489	2,569	1,187	9,334	1,057	433	12,691	717	2,942	2,240		

Appendix 1 - Line Failure Analysis, the Green Cells display lines that can fail in that turn without shedding any load on average

```
Line failures:
Line    F_BUS   T_BUS
3       3       6
Line failures due to cascade:
Round   Line    F_BUS   T_BUS
1:      29      17      18
2:      11      1       9
2:      20      16      15
2:      25      1       11
3:      5       5       8
3:      10      8       9
3:      12      7       4
3:      13      20      12
3:      17      12      19
3:      18      9       15
3:      19      14      19
3:      23      14      11
3:      27      20      16
3:      28      9       12
```

Appendix 2 - We noticed when running no constraints (N-0) that when line 3 failed it took out half of the entire system with it. Could have been a one off thing but we wanted to make note of it as it could be significant.