

## **August 14, 2003 Outage Sequence of Events U.S./Canada Power Outage Task Force September 12, 2003**

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This is an outline of significant physical and electrical events that occurred in a narrow window of time, before and during the cascade that led to the blackout of August 14, 2003. This outline reviews events beginning at approximately noon on that day, to provide a "picture" of the sequence of events and how the grid situation evolved over the afternoon. It focuses chiefly on events that occurred on major transmission facilities (230 kilovolts and greater) and at large power plants.

This outline does not attempt to present or explain the linkages between the sequences of events that are described. Determining those linkages will require additional intensive analysis over the weeks to come. In the coming weeks, our experts will continue to analyze data from:

- the thousands of transmission line events that occurred on the 138 kV system and on lower voltage lines over the several hours before and during the grid's collapse
- the hundreds of events related to power plant interactions with the grid during this period
- the conditions and operations on the grid before noon. Many things happened well before noon — including reactive power and voltage problems and flow patterns across several states — that may be relevant in a causal sense to the blackout.
- any actions taken, or not taken, by system operators prior to or during the outage.

The U.S./Canada Power Outage Task Force investigation is looking at all of the above factors and more in order to refine these data and dig deeper into what happened and why.

This timeline is not intended to indicate and should not be assumed to explain why the blackout happened, only to provide an early picture of what happened. It is not intended to indicate and should not be assumed to assign fault or culpability for the blackout. Determining the specific causes of these failures requires a thorough and professional investigation, which the bi-national investigative team has undertaken. The above concerns and explanations will be addressed in future reports prepared by the investigative team and issued by the Joint U.S./Canada Task Force.

Note: The information in this report is based on what is known about the August 14, 2003 blackout as of September 11, 2003, and is subject to change based on further investigation of this event.

### August 14, 2003 Outage Sequence of Events

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This report provides the sequence of some of the significant events that led to the blackout of the electric systems in the Mid-west and Northeast United States and eastern Canada on August 14, 2003. This explanation is intended to provide a general understanding of how the blackout evolved; it does not include every detail that is relevant and necessary to fully understand the root causes of the blackout. Such details are within the thousands of records of data that need further analysis. Those data records include circuit breaker operations, power plant startups and shutdowns, voltage changes, power flow shifts, and load shedding. A joint team from the United States and Canada is conducting a thorough investigation of the blackout and will provide appropriate details in a future report.

#### ***Event Times***

The times listed in this summary were derived from the “time stamp” that accompanied each data record. Whenever a circuit breaker opens to disconnect a transmission line or closes to reconnect a line, or generating unit is brought on line or off, or voltage exceeds a specified limit, the time that event occurred is recorded to the nearest second (and sometimes to the fraction of a second).

In some cases, the investigators discovered that these time stamps were not accurate because the computers that recorded the information became backlogged, or the clocks from which the time stamps were derived had not been calibrated to the national time standard. Investigators must determine which events are accurately time-stamped, and build from those events to cross-check other system events from multiple sources to verify the precise time for each event. Some of these events are still not known to the exact second.

All times in the chronology are in Eastern Daylight Time.

#### ***Voltage Collapse***

One of the characteristics of the August 14 blackout was an apparent “voltage collapse” that occurred on portions of the transmission system surrounding and within the northern Ohio and eastern Michigan load centers. Transmission system voltage is needed to transfer electric power from the generation stations to the load centers, and is somewhat similar in function to water main pressure. Reactive power is the component of total power that assists in maintaining proper voltages across the power system. Sufficient voltage is maintained by supplying the transmission system with reactive power from generating stations and static devices called capacitors. Lightly-loaded transmission lines also provide reactive power and help sustain system voltage. Conversely, customer loads such as motors and other electromagnetic devices consume reactive power, as do heavily loaded transmission lines. Therefore, as transmission lines become more heavily loaded, they consume more of the reactive power needed to maintain proper transmission voltage.

Reactive power cannot travel long distances because it meets considerable resistance over the transmission lines. Therefore, reactive power sources need to be close to the point of reactive power demand — for example, near the load centers. When heavily loaded transmission lines disconnect, the lines that remain in service automatically pick up portions of flow from the disconnected line, which increases the reactive power consumed by these lines. When reactive supply is limited, the increased loading will cause a voltage drop along the line. If reactive supply is not provided at the end of the line, the voltage could fall precipitously. At that point, the transmission system can no longer transfer electric power from distant generation to energy users in load centers.

## Initial Blackout Timeline

In some instances, the reactive power demand within an area is too great for the local generating units to supply. In those cases, the units can trip off line (automatic separation or shut-down), either from reactive power overload, or because the system voltage has become too low to provide power to the generators' own auxiliary equipment, such as fans, coal pulverizers, and pumps.









The power system is designed to ensure that if conditions on the grid (excessive or inadequate voltage, apparent impedance or frequency) threaten the safe operation of the transmission lines or power plants, the threatened equipment automatically separates from the network to protect itself from physical damage. Physical damage, if allowed to occur, would make restoration more difficult and much more expensive.

### Pre-blackout Conditions

Most of the events that appear to have contributed to the blackout occurred during the period from about noon EDT until 4:13 p.m. EDT. Generation and transmission operating events plus scheduled interchange through the systems in the region may have affected events later in the day. The investigators are studying these events beginning at 8 a.m. on August 14 to determine whether they were significant to the blackout.

### Map Key

The key on the right explains the lines and symbols on the maps that accompany this description of events. An “open path” or “open line” means that one or more transmission lines can no longer carry electricity between two areas; a “generator trip” means the generator separates from the grid and stops producing electricity.

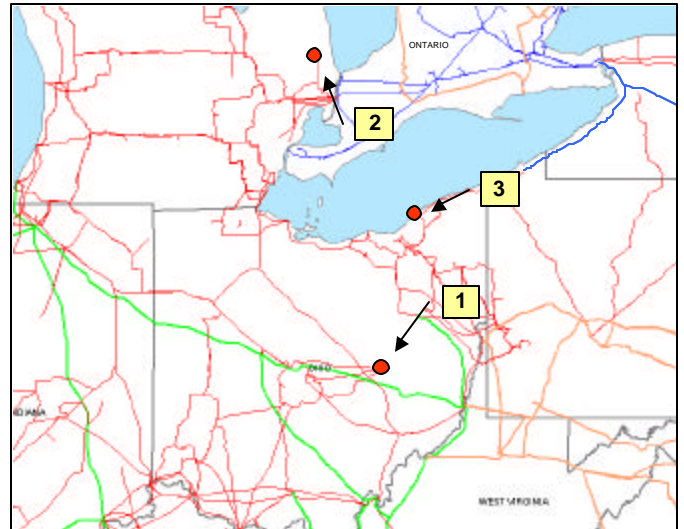
Transmission Lines	Events
 765 kV	 Line opening
 500 kV	 Path opening
 345 kV	 Generator trip
 230 kV	 Event number

### Events Leading to the Blackout

12:05:44 – 1:31:34 PM – Generator trips

1. 12:05:44 – Conesville Unit 5 (rating 375 MW)
2. 1:14:04 – Greenwood Unit 1 (rating 785 MW)
3. 1:31:34 – Eastlake Unit 5 (rating: 597 MW)

Conesville plant is in central Ohio and Greenwood plant is north of the Detroit area. Greenwood Unit 1 tripped at 1:14:04 and returned to service at 1:57. Eastlake Unit 5 is in northern Ohio along the southern shore of Lake Erie and is connected to the 345 kV transmission system. These generating unit trips (shutdowns) caused the electric power flow pattern to change over the transmission system.



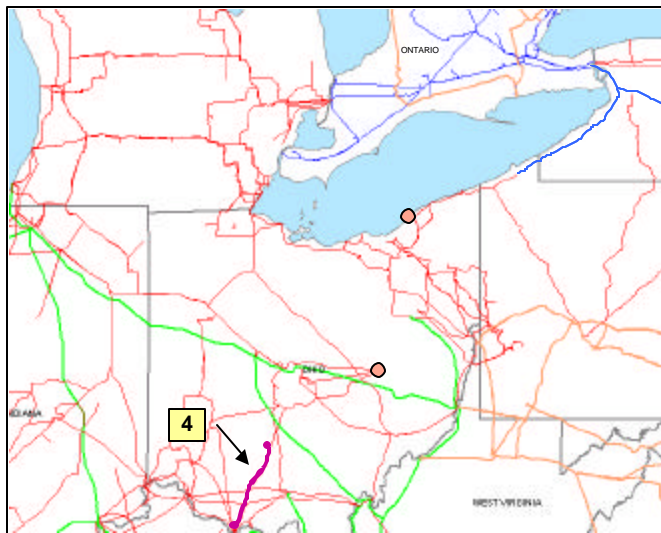
## Initial Blackout Timeline

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2:02 PM – Transmission line disconnects in southwestern Ohio

4. Stuart – Atlanta 345 kV

This line is part of the transmission pathway from southwestern Ohio into northern Ohio. It disconnected from the system due to a brush fire under a portion of the line. Hot gases from a fire can ionize the air above a transmission line, causing the air to conduct electricity and short-circuit the conductors.



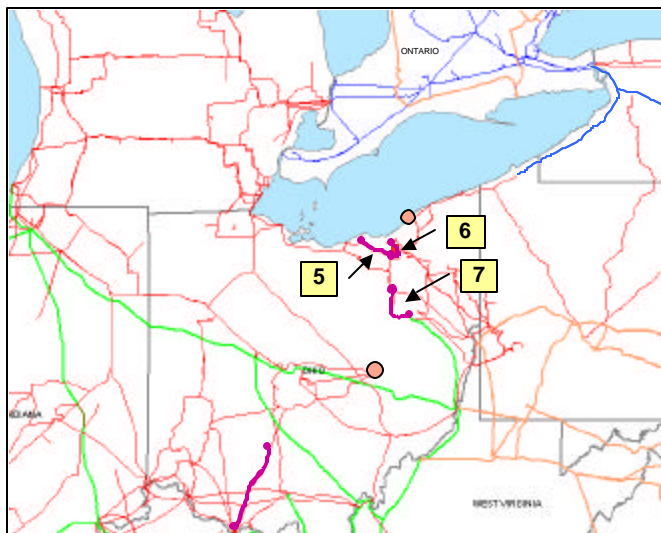
3:05:41 – 3:41:33 PM – Transmission lines disconnect between eastern Ohio and northern Ohio

5. 3:05:41 – Harding-Chamberlain 345 kV

6. 3:32:03 – Hanna-Juniper 345 kV

7. 3:41:33 – Star-South Canton 345 kV

These three transmission lines are part of the pathway into northern Ohio from eastern Ohio. At this time, the reason for the Harding-Chamberlain line going out of service is unknown. The Hanna-Juniper line contacted a tree, creating a short-circuit to ground that caused the line to disconnect itself. The Star-South Canton line had disconnected and reclosed twice earlier in the day, but the significance of those events is not yet clear.



With these lines disconnected, the effectiveness of the transmission path from eastern Ohio into the northern Ohio area was reduced. The electricity that had been flowing over these lines instantly began flowing over other transmission lines, including the underlying 138 kV systems, that connect northern Ohio to the grid. However, this new power flow pattern began to overload those other lines as well. As voltage was dropping, demand of about 600 MW disconnected in the northern Ohio area from industrial customers (whose motors dropped off line due to low voltage) and distribution-level customers who were disconnected automatically from the 138 and 69 kV transmission system.

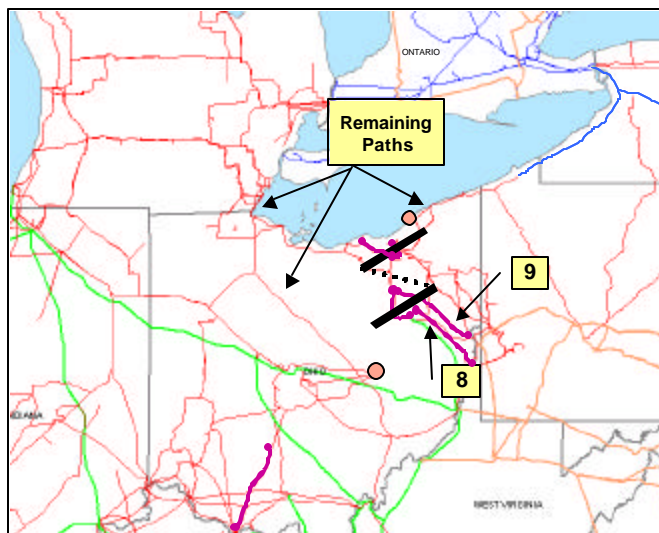
## Initial Blackout Timeline

3:45:33 – 4:08:58 PM – Remaining transmission lines disconnect from eastern into northern Ohio

8. 3:45:33 – Canton Central-Tidd 345 kV

9. 4:06:03 – Sammis-Star 345 kV

Canton Central-Tidd disconnected at 3:45:33 and reconnected 58 seconds later. However, the Canton Central 345/138 kV transformers disconnected and did not reconnect, isolating the 138 kV system from the 345 kV support at the Canton Central substation. The Sammis-Star 345 kV line then disconnected at 4:06:03, which completely blocked the 345 kV path into northern Ohio from eastern Ohio. This left only three paths for power to flow into northern Ohio: 1) from northeastern Ohio and Pennsylvania around the southern shore of Lake Erie, 2) from southern Ohio (recall, however, that part of that pathway was severed following the Stuart-Atlanta line trip at 2:02), and 3) from eastern Michigan. This also substantially weakened northeast Ohio as a source of power to eastern Michigan, making the Detroit area more reliant on the west-east Michigan lines and the same southern and western Ohio transmission lines.



During the period 3:42:49-4:08:58, multiple 138 kV lines across northern Ohio disconnected themselves. This blacked out Akron and the areas west and south.

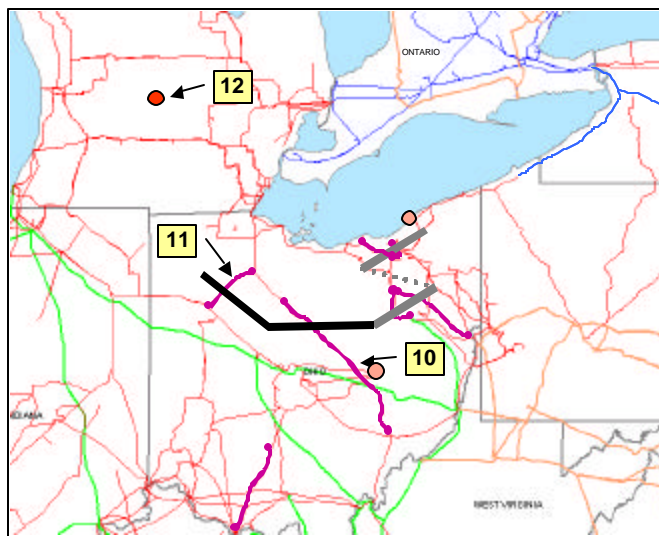
4:08:58 – 4:10:27 PM – Transmission lines into northwestern Ohio disconnect, and generation trips in central Michigan

10. 4:08:58 – Galion-Ohio Central-Muskingum 345 kV

11. 4:09:06 – East Lima-Fostoria Central 345 kV

12. 4:09:23-4:10:27 – Kinder Morgan (rating: 500 MW; loaded to 200 MW)

When the Galion-Ohio Central-Muskingum and East Lima-Fostoria Central transmission lines disconnected, this blocked the transmission paths from southern and western Ohio into northern Ohio and eastern Michigan. Thus the combined northern Ohio and eastern Michigan load centers were connected only by the transmission lines from: 1) northeastern Ohio and Pennsylvania along the southern shore of Lake Erie; 2) western Michigan via the west-east lines that cross the state; and 3) Ontario. Eastern Michigan was connected to northern Ohio only by three 345 kV transmission lines near the southwestern bend of Lake Erie.



The Kinder Morgan generating unit tripped (shut down) in central Michigan (loaded to 200 MW).

## Initial Blackout Timeline

Power flows became heavy from Indiana and over the west-east Michigan transmission lines to serve loads in eastern Michigan and northern Ohio.

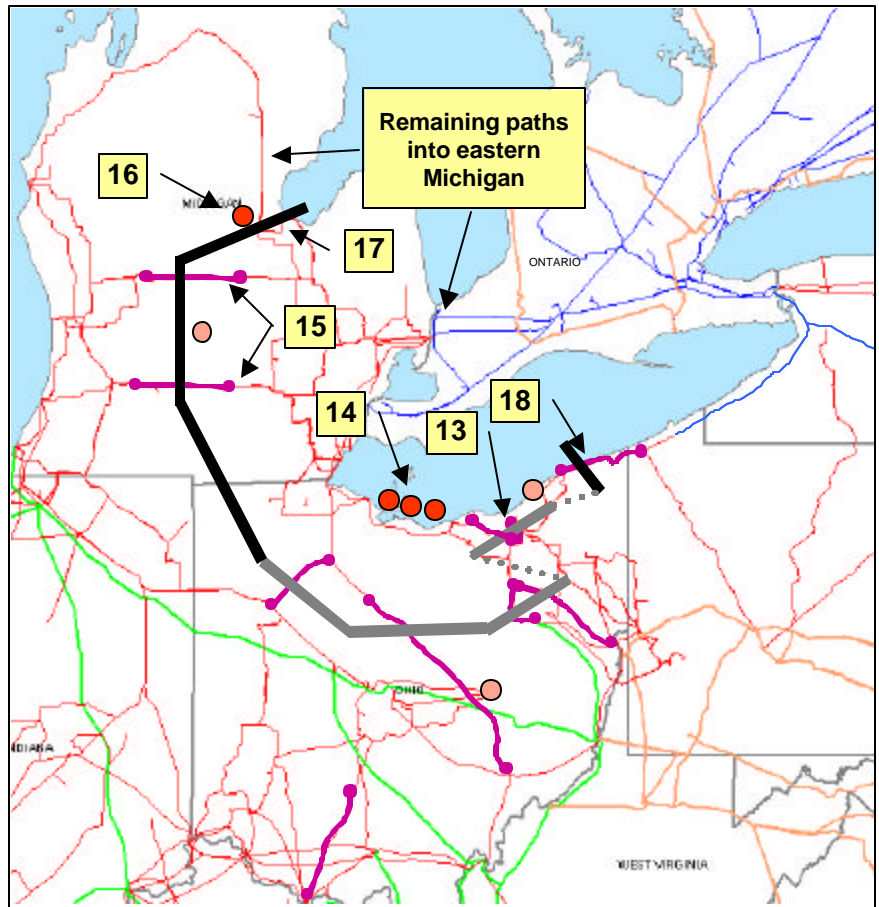
The reduced transmission capacity serving the northern Ohio load centers resulted in the transmission voltage becoming depressed in that area as load exceeded the rapidly declining power delivery capability.

At about 4:09, the Eastern Interconnection frequency rose by 0.020 – 0.027 Hz, which represents a demand loss in the range of 700 – 950 MW.

4:10:00 – 4:10:38 PM – Transmission lines disconnect across Michigan and northern Ohio, generation trips off line in northern Michigan and northern Ohio, and northern Ohio separates from Pennsylvania

13. 4:10 – Harding-Fox 345 kV
14. 4:10:04 – 4:10:45 – Twenty generators along Lake Erie in northern Ohio (loaded to 2174 MW total)
15. 4:10:37 – West-East Michigan 345 kV
16. 4:10:38 – Midland Cogeneration Venture (loaded to 1265 MW)
17. 4:10:38 – Transmission system separates northwest of Detroit
18. 4:10:38 – Perry-Ashtabula-Erie West 345 kV

Twenty generators (loaded to 2174 MW) tripped off line along Lake Erie during the period 4:10:04 – 4:10:45. The loss of this generation increased the power flows into the northern Ohio and eastern Michigan load centers on the remaining paths, which included the west-east transmission lines that cross Michigan.



The west-east Michigan 345 kV paths then disconnected at 4:10:37, leaving eastern Michigan connected by only a circuitous path around northern Michigan that disconnected one second later, and the connections to Ontario and northern Ohio. Investigators are still studying the power flows that resulted.

At 4:10:38, the Midland Cogeneration Venture (MCV), loaded to 1265 MW, tripped off line.

## Initial Blackout Timeline

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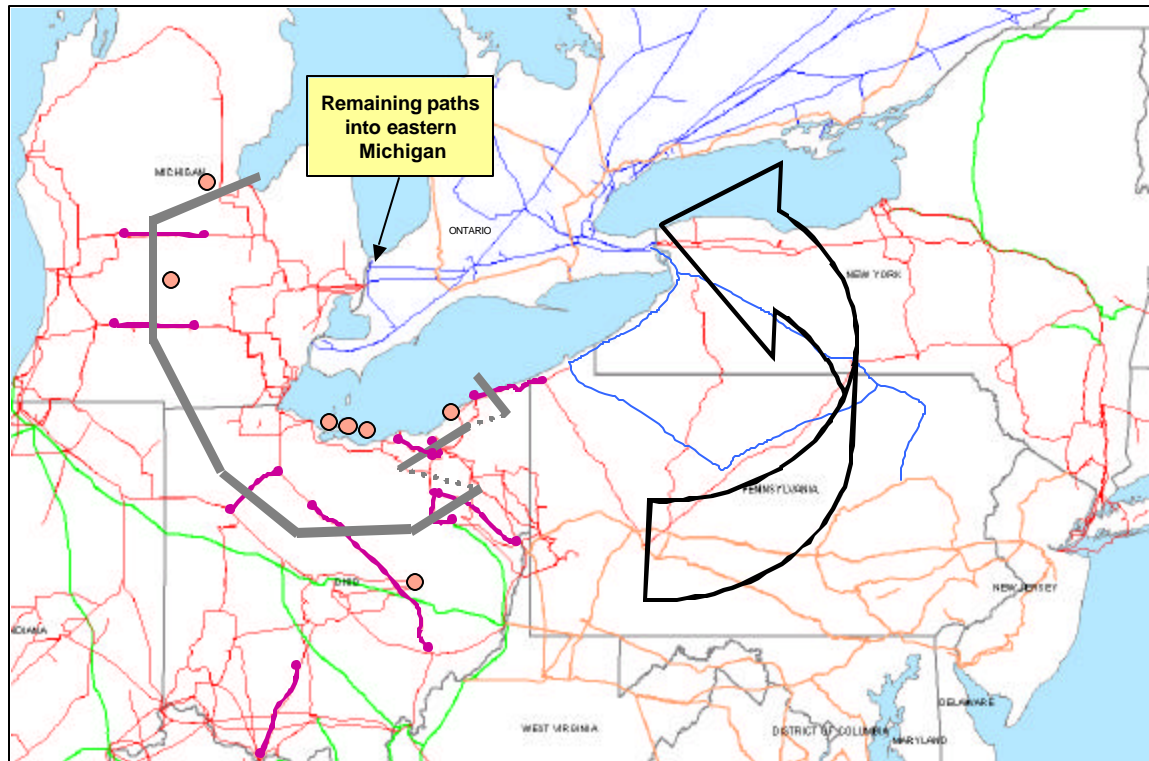
The MCV generation trip imposed heavier flows on the remaining transmission system, and left eastern Michigan and northern Ohio with very depressed voltages. The remaining transmission paths into the Detroit area from the northwest separated.

At 4:10:38, the Perry-Ashtabula-Erie West 345 kV transmission line tripped, severing the path into the northern Ohio area from Pennsylvania along the southern shore of Lake Erie.

### **Summary of the Situation at 4:10:38**

When the Perry-Ashtabula-Erie West 345 kV transmission line disconnected at 4:10:38, the entire eastern Michigan and northern Ohio load centers had little generation left available to them and the voltage was declining. The only connection between those load centers and the rest of the Eastern Interconnection was at the interface between the Michigan and Ontario systems. Also, the frequency was declining in northern Ohio in those areas that had separated from the Interconnection.

When the transmission lines along the southern shore of Lake Erie disconnected, the power that had been flowing along that path immediately reversed direction and began flowing in a giant loop counterclockwise from Pennsylvania to New York to Ontario and into Michigan.



We now turn our attention to the Pennsylvania, New York, Ontario, Québec, and Maritimes areas.

## Initial Blackout Timeline

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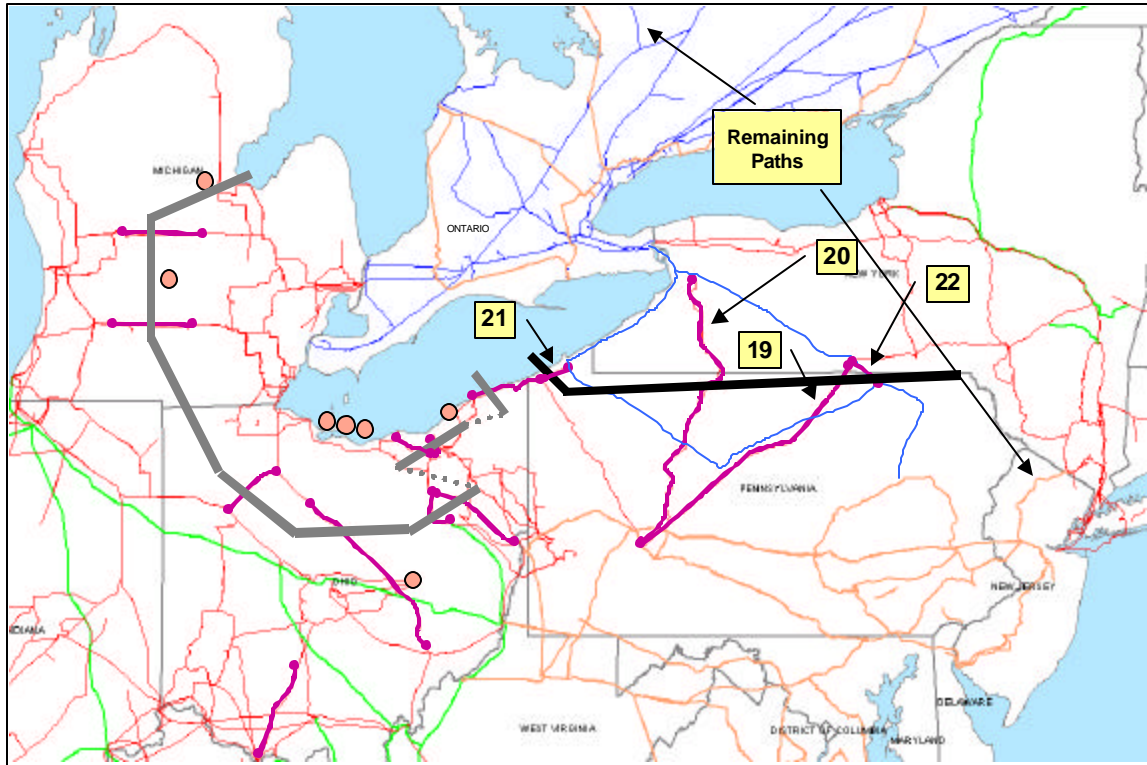
4:10:40 – 4:10:44 PM – Four transmission lines disconnect between Pennsylvania and New York

19. 4:10:40 – Homer City-Watercure Road 345 kV

20. 4:10:40 – Homer City-Stolle Road 345 kV

21. 4:10:41 – South Ripley-Dunkirk 230 kV

22. 4:10:44 – East Towanda-Hillside 230 kV



Responding to the surge of energy flowing north out of Pennsylvania through New York and Ontario into Michigan, these four lines disconnected within four seconds of one another and separated Pennsylvania from New York.

At this point, the northern part of the Eastern Interconnection (which still included the rapidly dwindling load in eastern Michigan and northern Ohio) remained connected to the rest of the Interconnection at only two locations: 1) in the east through the ties between New York and New Jersey, and 2) in the west through the 230 kV transmission line between Ontario, Manitoba, and Minnesota.

Heavy power flows were moving northward over the New York-New Jersey ties.



## Initial Blackout Timeline

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4:10:41 PM – Transmission line disconnects and generation trips in northern Ohio

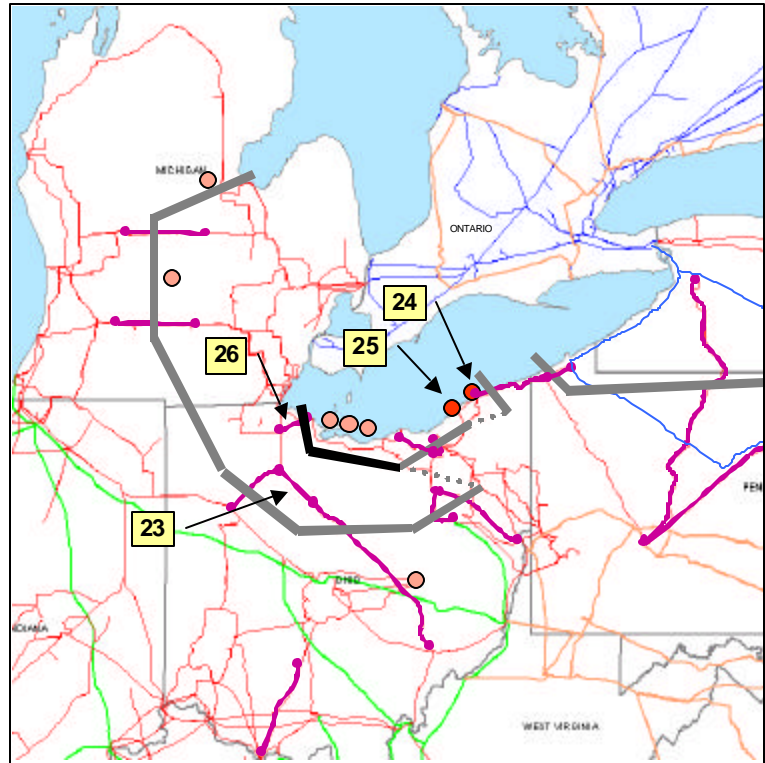
23. Fostoria Central-Galion 345 kV
24. Perry 1 nuclear unit (rated 1252 MW)
25. Avon Lake 9 unit (rated 616 MW)
26. Beaver-Davis Besse 345 kV

The Fostoria Central-Galion line forms part of the pathway from central to northern Ohio. That path was already blocked by the combination of the Galion-Muskingum-Ohio Central line disconnecting at 4:08:58, and the East Lima-Fostoria Central line disconnecting at 4:09:06.

Perry 1 nuclear unit, located on the southern shore of Lake Erie near the border with Pennsylvania, and Avon Lake 9, located near Cleveland, tripped off line at virtually the same time.

When the Beaver-Davis Besse 345 kV line, which connects the Cleveland and Toledo areas, disconnected, it left the Cleveland area isolated from the Eastern

Interconnection. Cleveland area load was disconnected first by automatic underfrequency load shedding, and finally by the disconnection of the transmission lines.

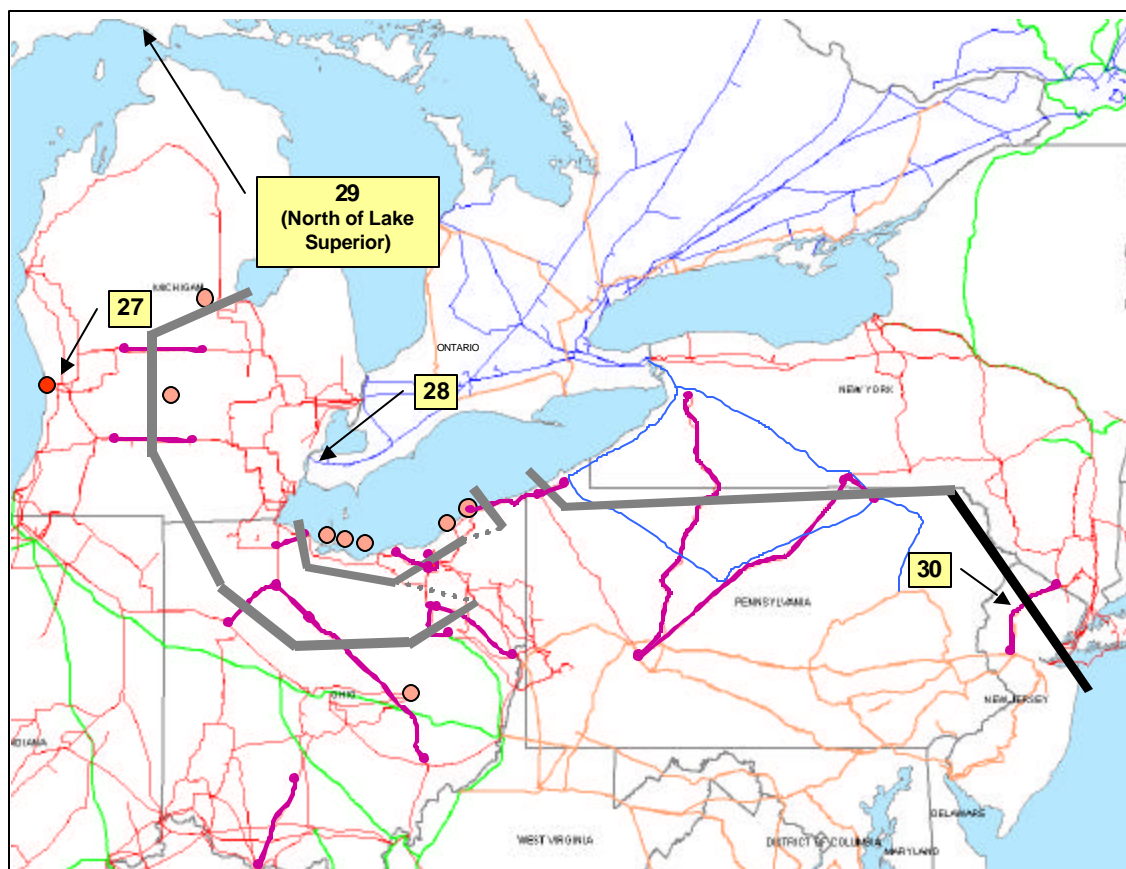


## Initial Blackout Timeline

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4:10:42 – 4:10:45 PM – Transmission paths disconnect in northern Ontario and New Jersey, isolating the northeast portion of the Eastern Interconnection

27. 4:10:42 – Campbell unit 3 (rated 820 MW) trips
28. 4:10:43 – Keith-Waterman 230 kV
29. 4:10:45 – Wawa-Marathon 230 kV
30. 4:10:45 – Branchburg-Ramapo 500 kV



At 4:10:43, eastern Michigan was still connected to Ontario, but the Keith-Waterman 230 kV line that forms part of that interface disconnected.

At 4:10:45, the Ontario system separated when the Wawa-Marathon 230 kV line disconnected along the northern shore of Lake Superior. The portion of Ontario to the west of Wawa remained connected to Manitoba and Minnesota.

At the same time, the Branchburg-Ramapo 500 kV line was now the remaining link between the Eastern Interconnection and the area ultimately affected by the blackout, and that line disconnected at 4:10:45 along with the underlying 230 and 138 kV ties in New Jersey. This left the northern part of New Jersey connected to New York. Pennsylvania and the remainder of New Jersey remained connected to the Eastern Interconnection.

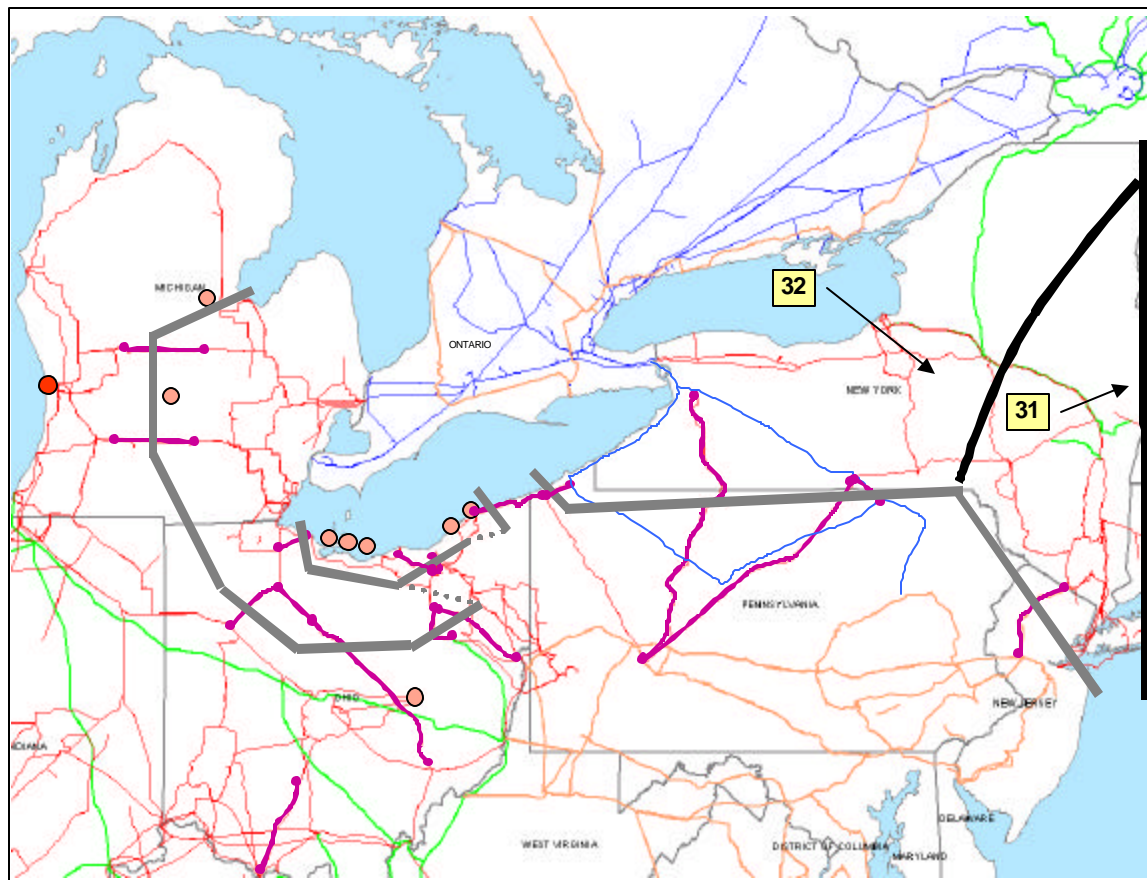
At this point, the Eastern Interconnection was split into two sections separated by an east-to-west line. To the north of that line was New York City, northern New Jersey, New York, New England, the Maritime

## Initial Blackout Timeline

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provinces, eastern Michigan, the majority of Ontario, plus the Québec system. To the south of that line was the rest of the Eastern Interconnection, which was not affected by the blackout.

4:10:46 – 4:10:55 PM – New York splits east-to-west. New England (except southwestern Connecticut) and the Maritimes separate from New York and remain intact.



During the next nine seconds, several separations occurred between the areas in the northern section of the Eastern Interconnection.

31. 4:10:46– 4:10:55 – New York-New England transmission lines disconnect

The ties between New York and New England disconnected during this period, and most of the New England area became an island with generation and demand balanced close enough that it could remain operational. However, southwestern Connecticut was separated from New England and remained tied to the New York system for about one minute.

32. 4:10:48 – New York transmission splits east-west.

The transmission system in New York split along an east-west line, with northern New Jersey and southwestern Connecticut connected to the eastern part of the New York system, and Ontario and eastern Michigan connected to the western part. During the next second, Ontario and New York would separate,

## Initial Blackout Timeline

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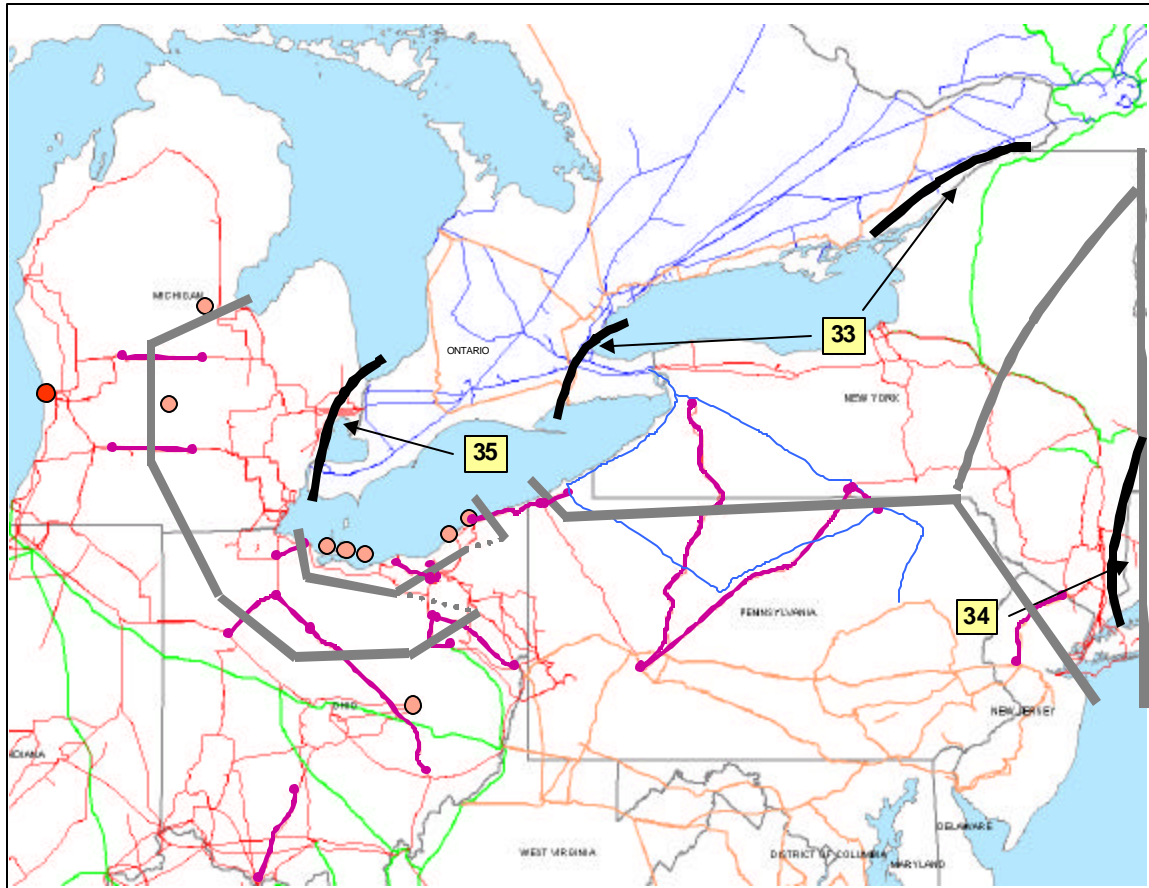
with 15% of the demand across New York state disconnected automatically. About 2500 MW of Ontario demand automatically disconnected as Ontario attempted to rebalance its system.

4:10:50 – 4:11:57 PM – Ontario separates from New York west of Niagara Falls and west of St. Lawrence. Southwestern Connecticut separates from New York and blacks out.

33. 4:10:50– The Ontario system just west of Niagara Falls and west of St. Lawrence separates from New York.

34. 4:11:22 – Long Mountain – Plum Tree 345 kV

35. 4:11:57 – Remaining transmission lines between Ontario and eastern Michigan separate



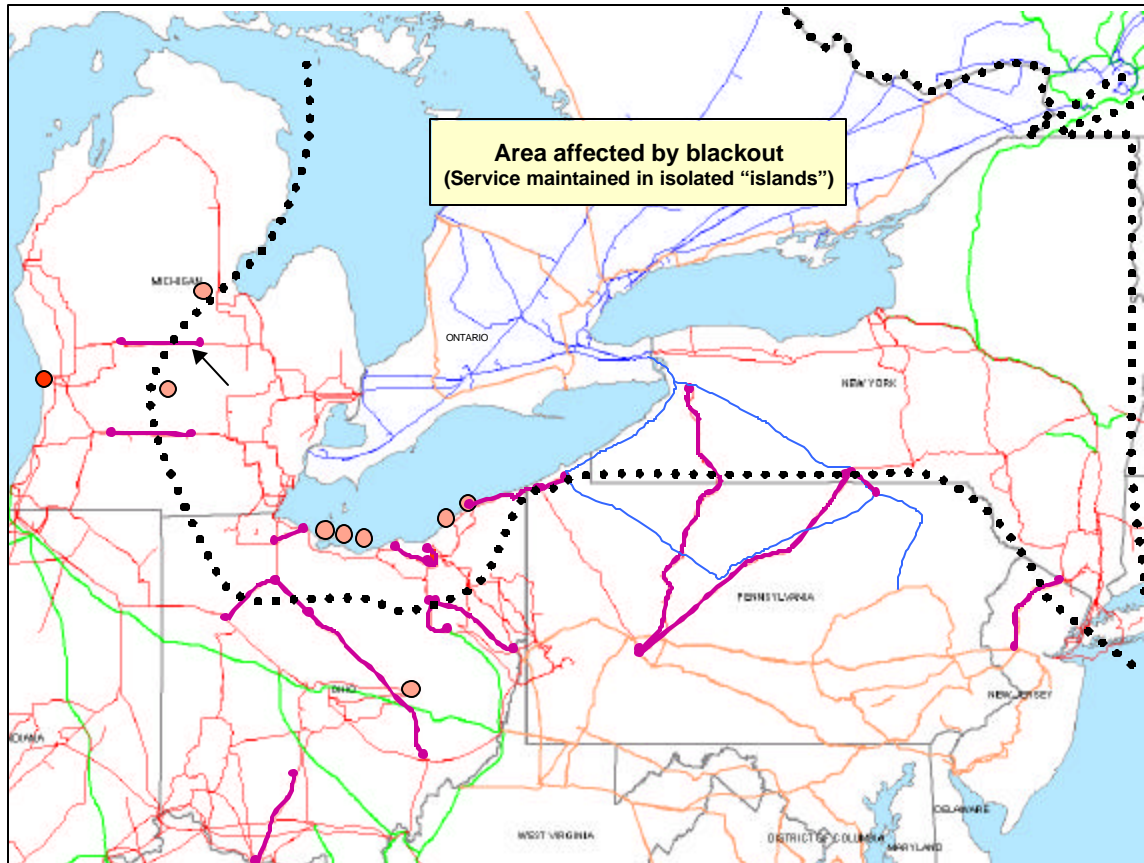
The Ontario-New York separation at 4:10:50 left New York's and Ontario's large hydro and some thermal generators at Niagara and St. Lawrence, as well as the 765 kV and direct current interties with Québec, connected to the New York system, supporting the demand in upstate New York just south of Lake Ontario. Three of the transmission circuits near Niagara automatically reconnected Ontario to New York at 4:10:56. Another 4500 MW of Ontario demand automatically disconnected. At 4:11:10, the Niagara lines disconnected again, and New York and Ontario again separated. Most of Ontario blacked out after this separation, leaving 22,500 MW of demand disconnected out of a total demand of about 24,000 MW. The eastern New York island blacked out with only scattered small pockets of service remaining. The western New York island continued to serve about 50% of the demand in that island.

## Initial Blackout Timeline

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When Long Mountain-Plum Tree (connected to Pleasant Valley substation in New York) disconnected, it left southwestern Connecticut connected to New York only through the 138 kV cable that crosses Long Island Sound. About 500 MW of southwest Connecticut demand was disconnected by automatic grid operations. Twenty-two seconds later the Long Island Sound cable disconnected, islanding southwest Connecticut and blacking it out.

4:13 PM – Cascading sequence essentially complete



The major portion of the northern section of the Eastern Interconnection (the area within the dotted line in the map above) was blacked out.

Some isolated areas of generation and load remained on line for several minutes. Some of those areas in which a close generation-demand balance could be maintained remained operational; other generators ultimately tripped off line and the areas they served were blacked out.

One relatively large island remained in operation serving about 5700 MW of demand, mostly in western New York. This service was maintained by generating stations south of Lake Ontario with Ontario generators at Niagara and St. Lawrence as well as the 765 kV and DC interties with Québec. This island formed the basis for restoration in both New York and Ontario.

### ***Conclusion***

This sequence of events for the August 14, 2003 blackout summarizes some of the many significant events that occurred before and during this widespread and complex system failure. It reflects events that have been identified and verified as of September 10, 2003. Much more data collection, analysis, and research must be completed before the Joint United States-Canada Power Outage Task Force will be able to state with confidence exactly what happened and why it happened. Our understanding of the events described here, and of those not yet fully catalogued, may change as the investigation progresses. The Task Force's future reports will include a more detailed timeline, and will address the causal relationships among these events.