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The Lagerlunda Collision and the Introduction of Color Vision Testing

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Abstract. In histories of vision testing, the origins of occupational screening for color blindness are often traced to a fatal railroad accident that occurred in Sweden on the night of 14–15 November 1875. The scene of the accident was the estate of Baron Lagerfelt in Östergötland, but the critical events were played out at Linköping (the normal passing place for the northbound and southbound expresses) and at Bankeberg (a small station to which the passing place was reassigned at a few minutes' notice). First to arrive at Bankeberg, the northbound express slowed almost to a halt, but then inexplicably accelerated forwards towards the Lagerlunda estate, despite a sequence of signals from the stationmaster, Uno Björkelund, and a lineman, Oskar Johansson. Soon after the accident, the ophthalmologist Frithiof Holmgren suggested that the engineer of the northbound express, Andersson, or his oiler, Larsson, had been color blind. Neither survived to be tested. Using the records of the subsequent trial and other archival materials, we have re-examined the role of color blindness in the Lagerlunda incident and conclude that the accident cannot be attributed to color blindness alone. Yet the accident undoubtedly had a central role in the introduction of color vision testing by European and North American railroads. To persuade the railroad management to introduce universal screening of employees for color blindness, Holmgren used a dramatic *coup de theatre* and some unashamed subterfuge. (**Surv Ophthalmol 57**:178–194, 2012. © 2012 Elsevier Inc. All rights reserved.)

Key words. color vision test • color blindness • railroad accident • Holmgren test

The Construction of a Legend

In the early hours of 15 November 1875, two express trains collided on a single-track railroad near Lagerlunda in Sweden. The site of the accident was the ancestral estate of Baron (*friherre*) Lagerfelt, 9 km west of the city of Linköping. Historical accounts of color vision testing almost always make reference to the Lagerlunda accident—to the role of color vision deficiency in the accident and the role of the accident in the introduction of systematic screening for color vision deficiency.

That color blindness caused the accident was first suggested by the ophthalmologist Frithiof Holmgren. In a letter to the State Railroad Board dated 25 September 1876, and reproduced in the newspaper *Aftonbladet* on 9 October, Holmgren speculated that either the engineer of the northbound express (A.T. Andersson) or his oiler (C.F. Larsson) was color

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deficient. Both Andersson and Larsson perished in the collision and thus were not directly tested. In his subsequent book *Color-Blindness in its Relation to Accidents by Rail and Sea* (1877), Holmgren is relatively guarded, writing:

> In what is called the Lagerlunda case or trial, instituted in consequence of a railway accident, of which Lagerlunda in Ostrogothia was the theater, November 15, 1875, and which at the time intensely excited public attention, testimony was adduced which led me to suppose that color-blindness was one of the principal causes of the accident.[26]

J.E. Jennings, sometime Consulting Oculist to the Missouri, Kansas, and Texas Railway System, was more confident when he wrote in 1896:

> In 1875 a serious railway accident occurred in Sweden, which intensely excited public attention. At the investigation that followed it was found that color blindness was one of the principal causes of the disaster. From this fact Professor Holmgren became convinced that the color-sense of the employés should be under official control…[31]

Wilibald Nagel, inventor of the anomaloscope, the definitive instrument for classifying color deficiencies, was still more certain in 1907:

> Zusammenstoss bei Lagerlunda in Schweden, 1875, 9 Tote. Sicher durch Farbenblindheit des Lokomotivführers herbeigefürt.[38] [Collision at Lagerlunda in Sweden, 1875, 9 dead. Undoubtedly caused by color blindness of the engineer.]

He was echoed by the ophthalmologists Stargardt and Oloff in their 1912 review:

> Bekannt is ja, dass im Jahre 1875 der schwedische Physiologe Holmgreen [sic] überzeugend nachwies, dass das Eisenbahnunglück bei Lagerlunda in Schweden, bei dem 9 Personen ihren Tod fanden, durch die Farbenblindheit des Lokomotivführers verursacht worden war.[49] [It is known that in the year 1875, the Swedish physiologist Holmgren convincingly proved, that the railway accident at Lagerlunda in Sweden, in which 9 people met their death, was caused by the color blindness of the engineer.]

And in a modern summary, the historian J.C. Burnham writes:

> In 1875, officials traced a serious railroad accident in Sweden to color blindness. A Swedish scientist then devised practical tests for railroad employees, and others used and improved on those tests. Only after many more such accidents all over the world, however, did testing for color blindness become general.[13]

Some commentators have been more cautious. One of these was the pioneer of ophthalmic genetics, Nettleship: His analysis of the accident, though not without error, is more detailed than most accounts in English, and he points out that Holmgren himself never went beyond hypothesis.[39] A 1912 discussion of the Lagerlunda incident by Allan Allander, a Swedish railroad professional, makes no reference at all to color deficiency.[6] Marking the centennial in 1975, R.G. Frey wrote:

> Es geht daraus hervor, dass nicht Farbenblindheit, sondern vorschriftswidriges Verhalten des Lokomotivführers und des Bahnhofsbeamten zum Zusammenstoss mit dem entgegenkommenden Zug führte.[21] [From this it can be concluded that not color blindness, but rather disobedience of the regulations by the engineer and the stationmaster, caused the collision with the approaching train.]

And similarly, Vingrys and Cole concluded in 1986:

> A congenital defect of colour vision has never been convincingly shown to be associated with any of these early accidents.[60]

We here offer a reanalysis of the role of color deficiency in the Lagerlunda incident and of the role of the accident in the introduction of screening in Sweden and other countries. We have drawn on the minutes of the trial that followed the accident,[24] the contemporary newspaper discussions, the internal telegrams of Statens Järnvägar (the State Railroad Company), and materials in the library and archive of the Sveriges Järnvägsmuseum at Gävle and in other private and public archives. We have also made spectroradiometric measurements of signal lanterns from the period.

The Trains and the Signals

One reason why the Lagerlunda incident captured public imagination was that the doomed trains were the two most prestigious in the Swedish system: the southbound night express from Stockholm to Malmö ('No. 1') and the northbound night express from Malmö to Stockholm ('No. 2'). The route is shown in Fig. 1. No third-class passengers were carried; and by the standards of 1875, the newly introduced night expresses were luxurious,

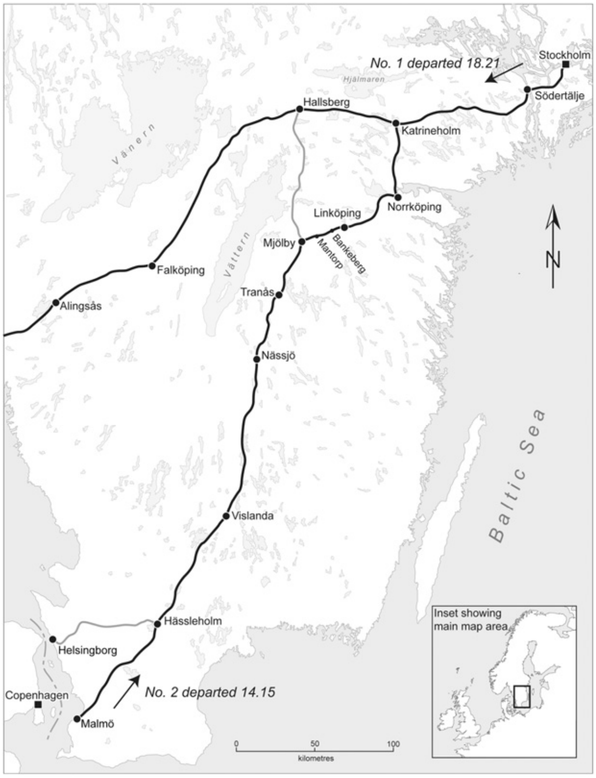


Fig. 1. Trunk lines of the Swedish State Railroad in 1875, showing the route from Stockholm to Malmö. The Lagerlunda estate lies between Linköping and the small station of Bankeberg. This schematic plan is based an official map published in 1876 as a supplement to the Report of the *Kongl. Styrelsen för Allmänna Väg-och Vattenbyggnader* and was prepared for us by Mr. D. R. Watson of the Cambridge University Geography Department.

Fig. 2. A surviving example of a locomotive supplied to the Swedish State Railroad by Beyer & Peacock of Manchester in 1866. This locomotive ("Göta") has the Beyer & Peacock serial number 627/1866 and was supplied in the same batch as the "Svea" (No. 629/1866), which was heading the up express from Malmö to Stockholm on the night of 14–15 November 1875. The "Göta" is here drawing 19th-century rolling stock. Note that the locomotive is significantly narrower than the cars and thus the engineer does not have a clear view back along the track.

with internal gas lighting, on-board lavatories, and, in the first-class cars, well-upholstered reclining seats.[62] And on that night, the two first-class cars of the northbound train were carrying a distinguished group of passengers, including the Baron Anders Koskull, the *Greve* and *Grevinna* Wachmeister, the *Konsul* Lyon, Edouard Anspach (former Belgian ambassador to Sweden), and Edward Joseph (a prominent London art dealer).[3] In each train, the two first-class cars were placed in the middle,[56] a position known to be the safest.

Both trains were drawn by powerful 2-2-2 engines supplied by Beyer and Peacock of Manchester, England[25,32] (Fig. 2), but braking and communication systems had not advanced in consort with locomotive design. Continuous braking systems—such as the Westinghouse vacuum system—had begun to be introduced in the United States after the disaster at Revere in August 1871[11] and were being actively advocated by railway inspecting officers in Britain,[34,40,47] but had not yet been adopted in Sweden. Instead, to stop his train, the engineer had to signal with brief blasts of the steam whistle, and the conductor in the baggage wagon then manually screwed down the brakes. And because a longer blast on the whistle could be used as a general warning, at a bend or at the sight of people on the track, the conductor could not react to the very first hearing of the whistle. It was with such equipment, and plenty of hubris, that luxurious expresses with gas-lit cars of wooden construction were being run at night on a single-track road covered by ice and snow.

Typical oil lamps used for signaling are shown in Fig. 3. The regulation hand signals in use at night in 1875 on the Swedish State Railroad were as follows:[6,50,62]

> *Stop:* A red lantern light; or any light moved up and down.
> *Proceed with caution:* A green lantern light; or any light moved slowly left to right.
> *All clear:* A white lantern light swung in a circle.

It is relevant that in 1875, there was no signal for 'back up.'[50]

Fixed signals were limited. A small station would have a single semaphore, which would have two arms (one for each direction) and which would be fitted with oil lamps to present colored aspects at night. The single semaphore was located by the station house.[62] So a stationmaster did not have separate semaphore signals for controlling the entry to, and passage through, the station—a limitation crucial to the Lagerlunda accident.

Fig. 3. Examples of railroad signal lamps from the period. By means of the handle at the top, an inner sleeve could be rotated to display red, green or clear glass. The light source was a wick, mounted above an oil reservoir and backed by a curved reflector.

An additional independent signaling system was in place on the Swedish railroad, however. Each few kilometers of track was covered by a *banvakt* or lineman. The duty of the lineman was to monitor his stretch of track and to be in position to signal to oncoming trains that the road ahead was clear. Trains were not to proceed without this signal. The linemen were a separate division of the railroad (the others being the station staff and the train personnel), and they had their own supervisors.

The signal lanterns carried by station workers and by linemen had a dual role: In the heavy darkness of a winter's night in rural Sweden, the lantern—set to clear—was needed for tasks such as walking along the track or clearing snow from switches. The glasses and reflectors of the lanterns quickly became sooty and needed regular cleaning to maintain their luminous output.

A variety of signals could be given with the steam whistle of the locomotive. These included the following:[50,62]

Train about to depart: -
Apply the brakes: - - -
Danger. Brake vigorously at once: - - -   - - -
Release brakes: —— -
General warning of approach of train to station, blind curve, tunnel, and so forth: ——————

Witness statements at the trial refer to an informal 'gate signal' of several short blasts, or of a longer blast followed by short ones, a signal not recognized by the Regulations but used by engineers to express roughly the meaning: '*Apply the brakes: The* **** *banvakt is not at his post by the gate.*'

Personnel on the train could signal to the engineer by pulling a cord that ran through the train and operated a bell in the tender.[62]

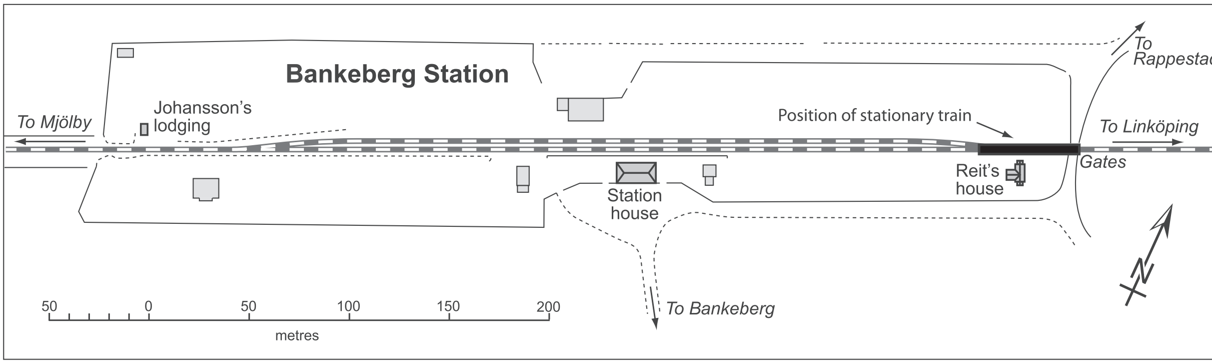
Preparations for an Accident

Although the collision was to occur on the Lagerlunda estate (Fig. 4, bottom), the critical events of the night were played out in the railroad station at Linköping (the normal crossing place for the two expresses) and at the small station of Bankeberg (later to be renamed Vikingstad). The southbound and northbound expresses were scheduled to arrive at Linköping at 00:27 and 00:28, respectively.[24,46] That night the southbound arrived almost on time, but the northbound was behind schedule. There had been heavy snow in the south (which blocked switches and reduced visibility). Also, according to an engineer and a fireman who had previously driven the northbound locomotive (the '*Svea*'),[2] the slide valves (*slider*) were leaking, a fault that would reduce the steam entering the boiler. Moreover, the fireman on the present night, Söderberg, had little previous experience of this route.[24]

The trainee stationmaster Michal, on duty at Linköping, was notified by telegram at 22:20 that the northbound had left Nässjö 52 minutes late. We believe that the timing of subsequent events is crucial to understanding the accident, and in Table 1 we reconstruct this from the primary sources. It should be consulted in conjunction with Fig. 1.

A second telegram reported that the northbound express had left Tranås at 23:35, still 51 minutes late. Michal now sent a messenger with the telegram to the home of Adolf Sjöstedt, the Superintendant of Traffic. Sjöstedt received the telegram at about midnight and arrived at the station some twenty minutes later. Meanwhile, the northbound was approaching Mjölby Junction, the last official stop before Linköping—and thus the last point at which its engineer, Anderson, could be informed of a change of crossing place.

Only at 00:30 was the first telegram sent to Bankeberg, asking for the stationmaster there, Uno Björkelund, to be awakened. On duty at Bankeberg was Jakob Jakobsson, 'extra rail worker'. Jakobsson had little training in operation of the telegraph. He was doing the night shift unsupervised for the first time,[46] he had been on duty since 05:00 the day before, and, according to all the contemporary accounts, was of low intelligence. Needless to say, there was some delay before he grasped what was wanted, but at around 00:40 or soon thereafter stationmaster Björkelund came on



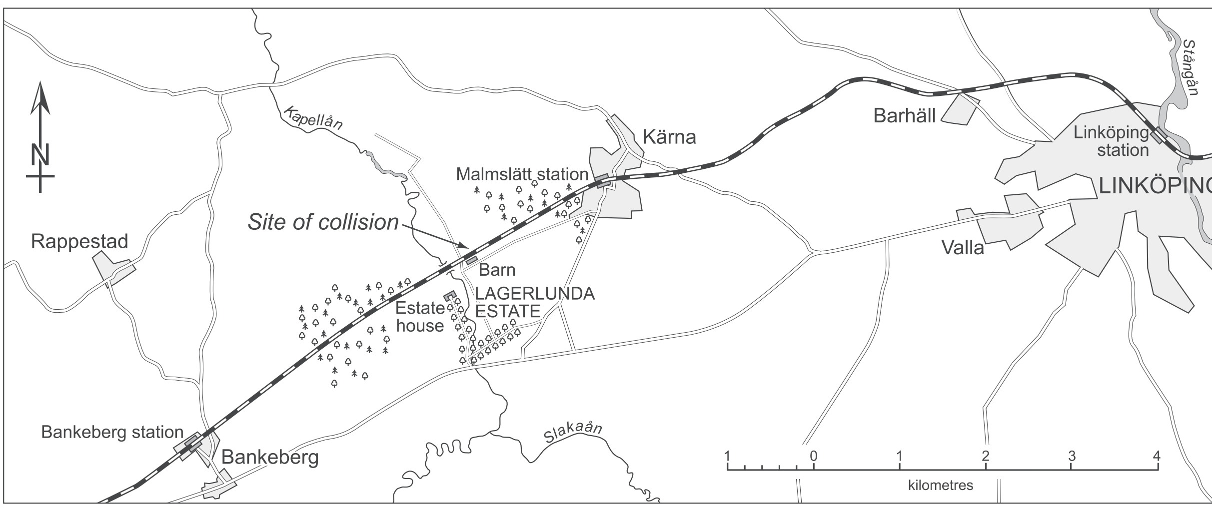


Fig. 4. *Top*: The layout of Bankeberg station. We have based this diagram on two surviving plans in the Swedish National Archives (These plans are undated, but they antedate the change of name to 'Vikingstad'). We show as a solid rectangle our estimate of the position of the northbound express when it briefly came to a halt near the eastern gate. The approximate position of Johansson's lodging is inferred from the protocol of the trial. *Bottom*: The route of the *Östra Stambanan* between Bankeberg and Linköping. Our estimate of the site of the collision is shown with an arrow.

the telegraph to ask the reason for the message. The Linköping operator replied, on his own initiative: *There was talk of a train meeting, but it is too late now, JM*. Meanwhile, at 00:41 the northbound left Mjölby Junction.[54] Its engineer, Andersson, would have been working his locomotive hard, hoping to make up time. There had been complaints by the Stockholm newspapers about the lateness of trains;[46] moreover, we can imagine that Andersson was anxious to get home to Katrineholm—where his new baby, his second child, was to be baptized later that day.[43]

Meanwhile in Linköping, at about 00:45, Traffic Director Sjöstedt talked to the engineer of the southbound, Sundqvist, about changing the crossing-place.[24] During this conversation, Michal twice came out to report that Björkelund was in the office at Bankeberg. Yet it was only at 00:56 that a telegram was finally sent to Bankeberg: *Retain train No. 2 until No. 1 has arrived. Sjöstedt*. At 00:58, Björkelund responded from Bankeberg with the correct formula: *Director of traffic, Lp. Train No. 2 will be retained until No. 1 arrives. Ubd.*[46] At about this moment, the northbound was already steaming through Mantorp, the last small station before Bankeberg.

What stationmaster Björkelund was not told was that the engineer of the No. 2, the northbound express, had not been notified of the change of meeting-place at the last scheduled stop, in Mjölby. It was common to give such notification, but it was not required by regulations. At the trial, Traffic Director Sjöstedt was to argue that train crews would become less alert to signals if notifications were always given.

At 01:03, on Adolf Sjöstedt's instruction, the southbound express left Linköping on the single track. Its engineer, Sundqvist, was uneasy, for *he* knew that Andersson, the engineer of the northbound, did not know of the change of meeting place. Hoping to reach Bankeberg first but having

TABLE 1

Time Sequence of Events that Preceded the Lagerlunda Collision

Time	Events at Linköping Station	Train No. 2 (northbound)	Events at Bankeberg Station
22:20	Michal, stationmaster, receives telegram from Nässjö that No. 2 left 52 min late.		
23:35		Leaves Tranås 51 min late	
	Telegram arrives from Tranås.		
~00:00	Traffic Director Sjöstedt receives telegram at his home.		
~00:20	Sjöstedt arrives at Linköping station.		
00:28		Arrives Mjölby Junction	
00:29	No. 1 (southbound) arrives at Linköping.		
00:30	Telegram to Bankeberg asking for stationmaster Björkelund to be wakened.		Station worker Jakobsson has difficulty understanding telegram. Fetches stationmaster Björkelund.
~00:40			Björkelund enquires reason for telegram. He is told: "There was talk of a train meeting but it's probably too late now."
00:41		Leaves Mjölby Junction	
~00:40–00:50	Sjöstedt has conversation with Sundqvist, engineer of No. 1, about changing crossing place. During this conversation, Michal twice reports that Björkelund is in the office at Bankeberg.		
00:56	Telegram to Bankeberg: "Retain train No. 2 until No. 1 has arrived. Sjöstedt"		
00:58			Björkelund sends Jakobsson to change east switch and telegraphs to Linköping: "Train 2 will be retained until No. 1 arrives".
		Passes Mantorp	Björkelund notified by telegram.
01:03	No. 1 (southbound) leaves Linköping.		Björkelund notified by telegram.
01:10		Arrives Bankeberg	

a railroadman's grasp of how far Andersson could have travelled, Sundqvist's strategy was to put on all steam for the first few kilometres, as far as the village of Malmslätt (Fig. 4, bottom), and thereafter to proceed with caution.[24,45] By this decision, Sundqvist probably saved many lives.

The Events at Bankeberg: A Story of Signals

Fig. 4 shows the layout of Bankeberg station. On an ordinary night, the east and west switches would have been locked in favor of the main track. The No. 2, as it approached from the southwest, would have alerted the station with the steam whistle. The station worker would have dropped the semaphore from red to green, indicating that the train could enter the station. Just beyond the eastern boundary of the station, the tracks crossed a road at a set of gates, and here the *banvakt* Oskar Johansson should have been in position to signal that the track towards Lagerlunda was clear. The 19-year-old Johansson, however, was not wholly reliable and on two occasions previously had been punished for not being present at the gates when a train arrived.[1,42,44]

On the critical night, with 10 or 12 minutes to prepare before the arrival of the No. 2, stationmaster Björkelund sent station worker Jakobsson to change the eastern switch (so that the No. 1 could run on to the side track) and told him then to return to the station house. Earlier that night, *banvakt* Johansson had borrowed Jakobsson's lantern to patrol the track. The eastern switch was close to the gates, and Jakobsson now demanded his lantern back from Johansson, so that he could clear snow from the switch. To retrieve his own lantern, the feckless Johansson set off towards the cottage where he lodged, at the opposite, western end of the station. As he passed the platform, he noticed stationmaster Björkelund standing by the semaphore, listening for the arrival signal of the No. 2.

With *banvakt* Johansson at the western end of the station boundary, busy lighting his lantern, the No. 2 entered the station boundary, moving fast.[46] Johansson now ran eastwards after the train, his lantern showing white light. We can readily imagine that his lantern was poorly maintained and thus reduced in luminosity. Johansson's later statements as to which way the lantern was pointing are conflicting: At first he claimed his lantern was pointing towards himself, but, when pressed, he admitted that the light may have been visible to the train.[24] He explicitly denied that the lantern could have been swung in a circular motion, but there remains the sinister possibility that a vertical component (due to the up–down motion that accompanies running) and a horizontal component (due to the swinging of the lantern in the hand) presented a resultant elliptical motion to observers on the train—and thus a simulation of the 'all clear' signal.

According to regulations,[6,50] stationmaster Björkelund was not permitted to use the semaphore to stop the train as it approached his station. He had to drop it to the green ("caution") position so that the train could enter the station, and the regulations required him to give the stop signal with a hand lantern. By his own account, however, he left the semaphore signal at red as long as possible, hoping thereby to slow the train. Nevertheless, the No. 2 approached the platform travelling much faster than Björkelund wished. With the green light of his hand lantern, he signaled the train to stop. The locomotive responded with a series of whistles, which the conductor in the last wagon, Laurentius Martin, interpreted as a signal to brake. Because Martin was screwing down the brakes, he could not watch for signals from the station at the same time. His colleague, baggagemaster Andersson, helped him turn the brake, and commented that probably the *banvakt* at the gates had fallen asleep on duty again.

On the platform, Uno Björkelund judged that the train was still going too fast. So he repeated his stop signal, now with his lantern set to red. The locomotive responded with more whistles, apparently indicating that his signal had been seen—although some witnesses perceived these blasts as the unofficial 'gate signal'. Satisfied that the train had seen his signal to stop, Björkelund now changed the light of his lantern to green again and held it still. He knew that the train was not permitted to leave the station without his explicit order.

The train coasted on; quite possibly, braking was hindered by snow or ice on the rails. By the time the locomotive came almost to a stop, it had entered the single-track section beyond the eastern station boundary and between the gates across the road. The wagons extended back to the switch (see Fig. 4). The switch, of course, had been set in favor of the No. 1, now on its way from Linköping; and more than one witness noticed the banging as the No. 2 crossed the switch—a clue that ought to have been sensed by the engineer.

As the northbound train had been approaching Bankeberg, Björkelund had sent station worker Jakobsson back to the east switch, to there await the arrival of the southbound. Running along the side of the track and with his lantern at green, Jakobsson arrived at the east switch in time to throw the switch to the main line before the last two wagons of the No.2 passed over it.[24] The conductor Martin, in the last wagon, now leaned out of the train to ask him if the gates were without signals. This Jakobsson confirmed, but sadly he had not grasped the situation well enough to inform Martin of the train meeting.

Meanwhile, *banvakt* Johansson, who should have been at the gates, had joined Uno Björkelund on the platform. One can imagine that by now Björkelund was anxious: the No. 2 was beyond the switch and the No. 1 was approaching from Linköping.

He did not have time to solve the problem, because the train barely seemed to stop before the locomotive gave the signal to release the brakes, and the No. 2 rapidly gained speed as it steamed off in the direction of Linköping. At the trial, Björkelund claimed that he now ordered *banvakt* Johansson to run after the train and stop it; Johansson claimed that he did not hear this, but acted on his own accord, changing his lantern to red while sprinting after the train. Johansson shouted to station worker Jakobsson to do likewise, but the slow-witted Jakobsson did not understand and decided to wait until Johansson arrived at the switch to see what he wanted. By the time Johansson arrived at the switch, the rear lights of the train shone dimly ahead. Engineer Andersson was making all steam through the worsening snow. He had five minutes to live.

Why did Andersson mysteriously restart without explicit orders? One design fault of trains of this era was that the locomotives were narrower than the wagons (Fig. 2). The standard width of passenger cars was 2,745 mm and that of baggage cars and post wagons at least 2,440 mm,[62] whereas the width of the footplate of the *Svea* was approximately 2,200 mm. So to see backwards to the platform at Bankeberg and to receive the stationmaster's signal, an engineer would need to leave his normal position on the left of the locomotive and lean out from the right side of the footplate—or actually dismount.[2] Yet all witnesses said the No. 2 came to a stop only very briefly, if at all. Engineer Andersson may have relied on a report from the oiler Larsson, who was in the front baggage car immediately behind the tender of the locomotive.[5,46] In the same car was baggagemaster Henrik Pamp, who survived the collision, though seriously injured. After the first set of brake whistles, according to Pamp, the oiler Larsson had suggested that the signals were probably given because the station workers had overslept. When the signals were repeated, Larsson looked out through the window on the south side (the side that gave a view back towards the station house) and said a man was running after the train showing ‘all clear’. Larsson then called out to engineer Andersson three times “It’s the all clear.”[5,24,46] This unofficial message may have been all that the frustrated engineer needed to restart his train. But what had the oiler Larsson seen? Did he see a white light describing a circle as Johansson ran along the track from the west? Or did he judge as white the signal light that Björkelund was showing from the platform?

Why did the conductor Martin, in the last wagon, subsequently neglect the red signal shown by Johansson as he ran after the train. At the initial enquiry[46] and at the trial,[24] Martin and the baggagemaster Anders Andersson both claimed that they kept a keen lookout for about one kilometer after releasing the brakes, but saw only two motionless green lights from the station, one from the semaphore and the other presumably from the stationmaster’s lantern. Martin first made this claim at the accident scene, where, “agitated and frightened,” he had been questioned by the engineer of the No. 1, Sundqvist, and by J.A. Petersen, stationmaster from Mjölby Junction.[24]

One other person observed the critical signals, and this was a woman and thus unlikely to be color blind. Hanna Reit, wife of the superintendant of *banvakter*, lived in a small house at the east end of the station, just inside the gates (see Fig. 4). During the day it was her task to attend to the gates and so she had a good understanding of the railroad signals. On the night of 15 November she was lying awake when she heard the northbound give a signal of several blasts of equal duration. Presuming these to be due to the gates, she got up and saw through one of the east facing kitchen windows that the train stood still by the gates. A very short while later the train continued with great speed, upon which a loud noise was heard from the eastern switch (difficult to explain if Jakobsson had in fact re-set the switch). At the eastern switch, a person stood showing a still green light. As the train started to move forward, Reit hurried into a room adjacent to the kitchen that had windows facing both east and west. There she saw that the rear lights of the train had passed the gates. Looking westwards towards the platform, she saw at first only a still green light but shortly thereafter another light, approaching and waving up and down. Initially she could not make out the color, but then saw it to be red. She judged the train was close enough to see the green light on the platform as well as the red light—although she of course was closer to the platform. By now the lineman, Oskar Johansson, was close: He was shouting “Stop!” and chiding the person by the switch for not having stopped the train. Reit now left the room, convinced that the train would back up, having seen the red light.[24] Although she could have had reason to protect the local staff at Bankeberg, Hanna Reit appears a competent witness.

Contrary to the claims of Nagel[38] and of Stargardt and Oloff,[49] if a member of the train personnel was color deficient, it is unlikely to have been the engineer Andersson. The strongest candidate is the oiler Larsson, who was to die of his injuries in Linköping the following night. It is possible that the conductor Martin and baggagemaster Andersson, who had the best view of the signals from the rearmost car, were both color deficient. The prior probability of this is low (~ 0.0064), but then we are dealing with an unlikely accident. Alternatively, Martin neglected his duty to look rearwards, and he and the baggagemaster conspired to lie to the subsequent enquiries.

Lagerlunda

By the time he came out of the wood by Malmslätt (Fig. 4), engineer Sundqvist had turned off the steam on No. 1 and was coasting at 20 km/h along the straight section of track.[24] At this moment, he saw the reflection of a flame in steam on the other side of the bridge across the Lagerlunda stream. He gave a signal to brake, opened the sand boxes, put the locomotive into reverse, and told fireman Wallner to jump. When he clearly saw the oncoming headlamps of the No. 2, Sundqvist leapt off.

The dreadful collision occurred at approximately 01:15. We estimate that the site was 400–500 meters east of the Lagerlunda stream (Fig. 4), near a barn belonging to Baron Lagerfelt (a barn is still on this site).[4,53] The people of Lagerlunda were brought to the scene by the thunderous noise of the collision, and soon had in operation the estate’s fire engine. Four kilometers away, in Bankeberg, the collision was audible as a rumble. Stationmaster Björkelund prepared a telegram: *T.D. Lp. [Traffic Director, Linköping] When train No. 2 arrived stop was waved with a red lantern, but regardless of this the train continued, there must have been a terrible collision since No. 1 had already* *left from Lp. Björkelund*; but the collision had cut the line, and the news could be telegraphed only by Mjölby in the south and then round a loop of stations via Katrineholm, reaching Linköping at 02:52.[46] The role of Arthur Rostron, captain of the *Carparthia*, is taken in the present story by J.A. Petersen, station-master at Mjölby, who organized a relief train with equipment and men, arriving at approximately 02:40[5] and sending the uninjured southbound passengers to catch the next connection at Mjölby. Traffic Director Sjöstedt in Linköping did not send out a relief train until about 04:00, waiting until confirmation of the accident was brought by engineer Sundqvist, who had come on foot along the track through the snow.[46]

The death toll from the Lagerlunda crash was nine and included crucial witnesses: Engineer Andersson, both the firemen (Wallner from the No. 1 and Söderberg from the No. 2), and Larsson, the oiler from the No. 2. Several second-class passengers and railroad employees were killed or injured;[62] none of the first-class passengers were badly hurt. Baron Koskull suffered a broken rib.[4] The *Greve* and *Grevinna* Wachmeister stayed to recuperate on the estate of their relatives, the Lagerfelts.[46] If only death and injury are considered, the Lagerlunda incident was not remarkable for its day. Scores of people were to perish in the wreck of the *SS Deutschland* less than three weeks later,[59] and typically over 1,000 people were killed each year in railroad accidents in Britain during the 1870s.[52] (In the four years to 1875 there were 5,231 such deaths.[34]) Yet the Lagerlunda collision was widely reported throughout the world.

One factor was the distinguished passenger list, another, the spectacular appearance of the wrecked locomotives. Photographs of the scene after the accident show the two locomotives mounted against each other (Fig. 5). The image that contributed most to national and international horror at the disaster was a sketch by a young, part-time illustrator for *Ny Illustrerad Tidning*, who was called from his classes in Stockholm on the morning of the 15th to join a train carrying senior railroad officials to the accident. This art-school student was Carl Larsson, later to become Sweden's most celebrated 19th-century painter. Larsson's sketch of the scene showed the arm of engineer Andersson still sticking out from the wreckage: "His whole chest was ripped open, a frightening sight."[33] Larsson's image (Fig. 6), reproduced by a woodcut process, was widely published in the foreign press.

Fig. 5. A photograph of the wrecked trains. This photograph appears to have been taken from south of the track, so that the locomotive of the No. 2, the *Svea*, is to the left.

The Causes of the Lagerlunda Collision

If color deficiency contributed to the Lagerlunda collision, it was far from being the sole cause. As is so often the case, an unhappy conjunction of factors had to come together to make the accident possible.

The causes of railroad accidents can be divided into four—not entirely exclusive—classes:[6]

1. acts of nature
2. mechanical failures
3. system failures

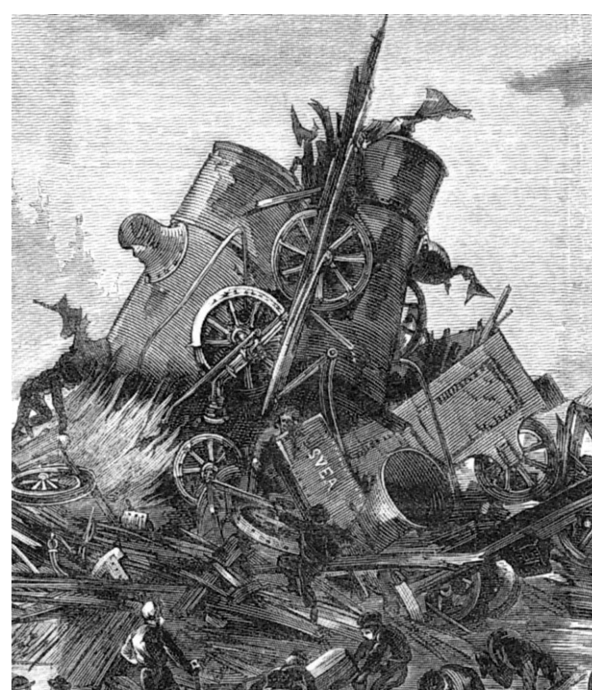


Fig. 6. Detail from Carl Larsson's sketch of the aftermath of the crash. Larsson arrived from Stockholm many hours after the collision and so he has used some imagination in this reconstruction. The sketch is drawn from the north, with the *Svea* to the right. The body of engineer Andersson (*center*) was still trapped in the wreckage when Larsson reached the scene.

4. Human error, such as visual or auditory misperception, inattention, lapse of memory, or disregard of regulations

All four classes can be identified in the Lagerlunda case. Nature played its part, in that the northbound express was delayed by heavy snow, stopping distances were increased by slippery track, the rear window of the conductor's wagon of the No. 2 was obscured by snow, and a light falling snow reduced visibility in the minutes before the collision—although these conditions were hardly unusual for Sweden in mid November.

Mechanical failure possibly had some role, in so far as the sliders were leaking on Andersson's locomotive:[2] The progress of the No. 2 during the night may have been less than optimal, Andersson and Söderberg may have spent more time working to keep up the fire and less time watching the road, and, critically, steam escaping at the front of the locomotive may have obscured the view from the cab as the train approached the platform at Bankeberg.

Four system weaknesses are prominent:

- There was no requirement that engineers should be notified at an earlier station of any change of meeting place.[6] Such a requirement was introduced by the *Statens Järnvägar* shortly after the Lagerlunda accident.[6]
- The single fixed signal did not distinguish between 'The train can safely enter the station and continue' and 'The train can safely enter the station, but must stop'.[6]
- No hand-signal was available for 'back up'. Such a signal was introduced by the *Statens Järnvägar* after 1877.[62]
- Engineers had developed an unofficial 'gate signal' that was similar to the signal they might give in response to a stop signal from a stationmaster.

But above all, a cascade of human errors can be identified:

- Although he was told by midnight that the No. 2 was behind schedule, Traffic Director Sjöstedt inexplicably waited until 00:56 to notify Bankeberg—giving Uno Björkelund and his inadequate staff only minutes to prepare for the trains' arrival.
- Björkelund formed the wrong mental model of the expectations of engineer Andersson.
- The *banvakt* Oskar Johansson was not at his post.
- Contrary to regulations, engineer Andersson departed from Bankeberg without explicit instructions from the stationmaster.[6] He also mysteriously failed to notice that he crossed a switch that was against him. In his first telegram notifying Stockholm of the accident, sent at 04:15 on 15 November, it was to Andersson that Traffic Director Sjöstedt attributed the collision.[55]
- The oiler Larsson may have been color deficient or may have misinterpreted a swinging lantern carried by the *banvakt* Johansson.
- The conductor Martin, in the rear brake wagon, may have been color deficient or may have neglected his duty to look back for signals from the station.

Table 1, constructed from the primary sources, suggests to us that a large part of the guilt must be carried by Traffic Director Adolf Sjöstedt, who recklessly delayed deciding on a change of meeting place. Subsequently, we analyze further the extent to which the lantern signals would have been confusable to the color deficient.

The Trial

In the Swedish legal system, criminal and civil processes were not separated. Thus the same court could judge criminal guilt and adjudicate on claims for damages by third parties. And whereas under British[12,23,34] and Prussian[48] law, a railroad company was subject to strict liability as a corporate body for injuries to its passengers, in Sweden only the individual employee could be held liable.[22]

The Lagerlunda case was heard by the *Hanekinds Härads Rätt* in an initial session beginning on 15 December 1875, and in further sessions in March, April and May 1876. The four defendants were: Adolf Sjöstedt (Traffic Director), Laurentius Martin (conductor on the northbound), Jakob Jakobsson (extra station worker at Bankeberg), and Uno Björkelund (stationmaster at Bankeberg). Mysteriously, the *banvakt* Johansson was not charged and was admitted as a witness. The following were the verdicts:

Traffic Director Adolf Sjöstedt. Not Guilty. "acted according to Chapter 2, §19 of the current Regulations of Duty of the Government's Railroad, and because no circumstances according to Chapter 2, §7 of the Regulations were shown during the investigation to give him reason to refrain from changing the meeting place, he cannot be regarded as responsible for the collision… and the defendant is therefore freed from responsibility and the obligation to pay reparations."

Conductor Laurentius Martin. Not Guilty. He was required by the Regulations to watch for signals, but from Hanna Reit's evidence it is not certain that he could have seen Johansson running with his red lamp.

Extra Station Worker Jakob Jakobsson. Not Guilty. He was authorized by the Regulations to inform the No. 2 of the change of meeting place, but had not worked at the station long enough to have a clear idea of how these things were handled.

Stationmaster Uno Björkelund. Guilty of neglecting his duties as an employee of the railroad company. To be dismissed from his post and imprisoned for six months. To pay 125,683 kronor to the railroad company in compensation for damage to company property. Also to pay 4,000 kronor to the widow and children of engineer Andersson, 125 kronor yearly to each of the four under-aged orphans of Assistant Traffic Director Frans Anrep [who was killed in the accident alongside his wife], and the costs of witnesses attending the court. The total damages are best judged in relation to Björkelund's salary as *stationsföreståndare*—which was 1,200 kronor per month.[51]

The court's decision did not pass without criticism at the time,[16] and the reader may share the conclusion of the present writers that Uno Björkelund was made a scapegoat by the management. No more than Adolf Sjöstedt had he explicitly broken a regulation. Engineer Andersson definitely had broken a regulation, but he had died horribly and had left two fatherless children.

Analysis of Signal Lamps

Could modern techniques ever throw fresh light on the role of color deficiency in the Lagerlunda accident? In principle, if surviving DNA were recovered from any of the *dramatis personae*, it would be possible to sequence the opsin gene array and reconstruct the phenotype, as has been done in the case of John Dalton himself.[29,37] This remains a remote possibility.

One thing we have been able to do is characterize in modern terms the chromaticities of the signal lamps that were in use and thus we can estimate the extent to which the signals would be confused by a dichromatic observer. At the Swedish Railroad Museum in Gävle, we were able to measure the emission spectrum from a lantern that still contained a little oil (of unknown age). Two separate measurements were made with a PhotoResearch 650 spectroradiometer and are shown in Fig. 7A. For a larger number of vintage lamps, we have measured the transmission spectra of the red and green glasses that are mounted on the inner, rotating sleeve of such lanterns. To make these measurements, we removed the sleeve from the outer casing of the lamp and placed it on a small light table (*Normlicht* Mini5000). The light table was covered with an opaque cover except for a disk-shaped central aperture that fitted the base of the sleeve of the lantern. Using the spectroradiometer, we measured the light emitted from the light table either through the clear aperture of the sleeve or through one of the colored glasses. By subtracting the second spectrum from the first we obtained the transmission spectrum of the colored glass (Fig. 7B). This could then be multiplied by the emission spectrum of the unfiltered oil lamp to estimate the emission spectrum with a given glass in place—the signal offered to the eye (Fig. 7C). By multiplying the latter by the sensitivities of the cones,[18] the relative excitations of the cones could be estimated.

To plot the chromaticities of the lamps, we use the MacLeod-Boynton diagram,[35] which has widely replaced the CIE diagram in visual science (Fig. 7D). It has the advantage that it makes explicit the relative excitations of the three types of cones, and its axes correspond to the signals extracted by the two main types of chromatically opponent neurons in the retina and lateral geniculate nucleus:[19,36]

- The horizontal axis relates to the signal carried by the midget retinal ganglion cells, which draw inputs of opposite sign (excitatory or inhibitory) from long- (L) and middle-wave (M) cones.
- The vertical axis relates to the signal carried by the small bistratified ganglion cells,[15] which draw excitatory input from short-wave (S) cones and inhibitory input from L and M cones.

Thus vertical lines in the diagram are confusion lines for tritanopes: Along such a line, only the signal of the short-wave cones is varying. Lines radiating from the origin are confusion lines for deuteranopes; and lines radiating from $x = 1$, $y = 0$ are confusion lines for protanopes. Examples of protan and deutan confusion lines are shown in Fig. 7.

The plane of the MacLeod-Boynton diagram is one of constant luminance for a normal observer, that is, the sum of L- and M-cone excitation is constant (S cones do not significantly contribute to luminance). The relative luminosities of the signal lights for protans and deutans cannot be directly represented in the diagram, but can be calculated by multiplying the signal spectra by the M- and L-cone sensitivities,[18] respectively. We show the results in Table 2.

From these measurements we can draw the following conclusions. At short distances, both protans and deutans should be able to distinguish the (very yellowish) 'signal white' from both red and green signals, owing to the greater excitation it gives

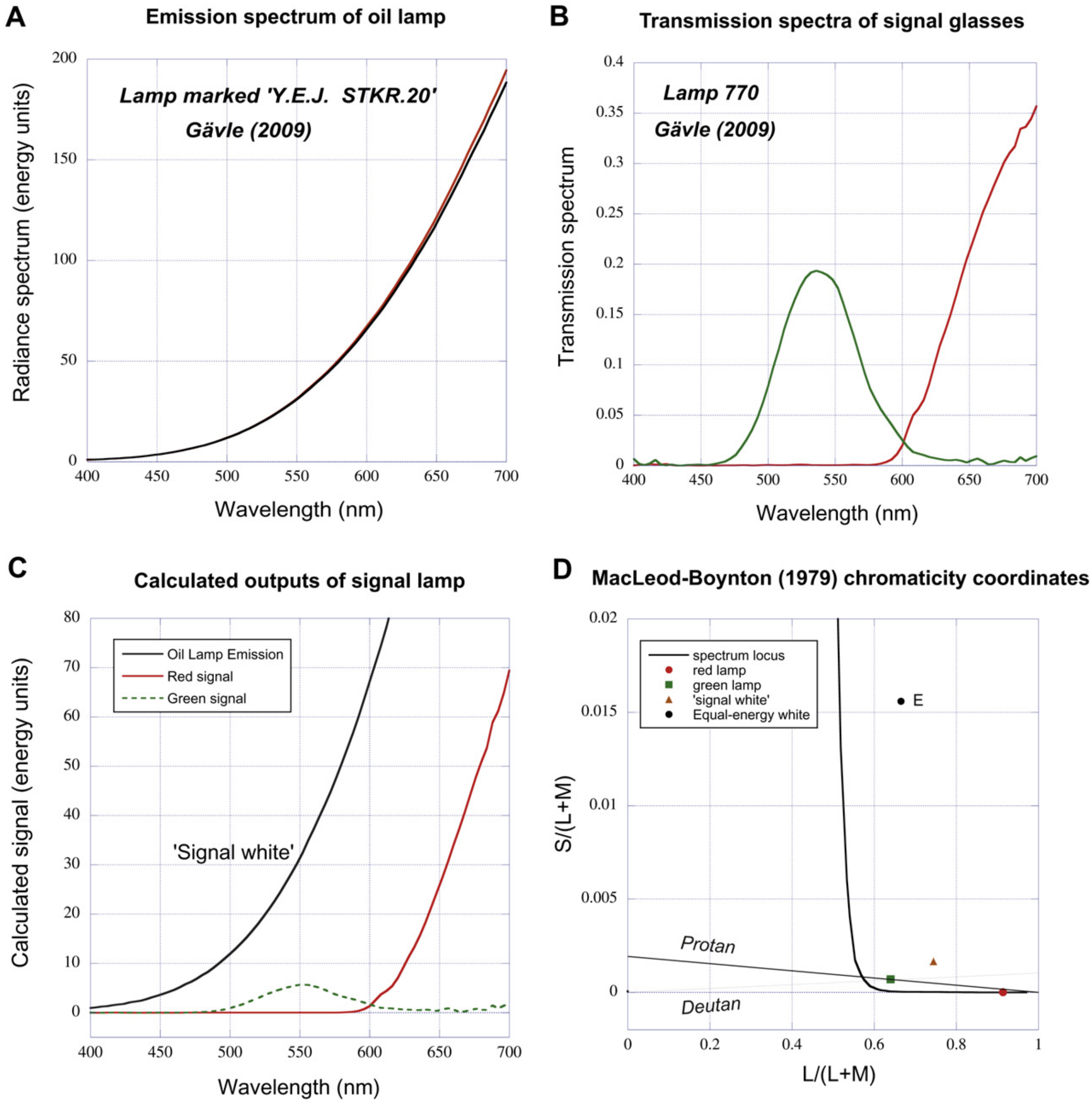


Fig. 7. *A*: Emission spectrum of a 19th-century oil lamp from the Swedish Railroad Museum at Gävle. Two separate measurements are shown by the black and red curves. *B*: Transmission spectra of the red and green glasses of an early railroad lamp. *C*: The red and green signal spectra calculated from the transmission spectra. The curve for 'signal white' is the unmodified emission spectrum from the first panel. *D*: The chromaticity coordinates of the signals plotted in the MacLeod-Boynton (1979) diagram. The horizontal axis of the graph represents the ratio of L-cone excitation to the sum of L- and M-cone excitation. The vertical axis represents the ratio of S-cone excitation to the sum of L- and M-cone excitation. These two ratios are thought to be extracted by morphologically distinct neurons in the retina and lateral geniculate nucleus[14,36] (see text). The symbol *E* indicates the coordinates of equal-energy white, and the curved solid line represents part of the spectrum locus (i.e., the chromaticities of monochromatic spectral lights). In this diagram, protan confusion lines radiate from $x = 1.0$, $y = 0.0$ and deutan confusion lines radiate from the origin of the graph. Examples of confusion lines are shown.

in the short-wave cones. At short distances, a protanope could probably distinguish the red and green lights only by their different luminosities (because they fall almost on the same confusion line), whereas a deuteranope could distinguish them by the short-wave cone component.

At a distance, however, matters are very different, because here foveolar and small-field tritanopia

TABLE 2

Relative Luminosities for Protanopes and Deuteranopes of the Red, Green, and 'White' Outputs of a Typical Signal Lamp

	Protan Luminosity	Deutan Luminosity
Red	4.52	47.79
Green	30.6	54.45
'White'	294.87	859.04

These estimates are in arbitrary units, but are obtained by multiplying the measured outputs of the lamp by the corneal sensitivities of middle-wave (protan) and long-wave (deutan) cones. Note that the red and green signals are of similar luminosity for the deutan but are very different for the protan.

come into play.[61,63,65] Owing to the sparseness of short-wave cones[10,17] and their absence from the center of the foveola, the normal eye becomes tritanopic for targets subtending less than 10–20 minutes of arc; and the dichromatic eye becomes monochromatic.[64] Thus we can be confident that red, green, and clear lights would not have looked different in hue to a dichromatic observer looking backwards to the Bankeberg station from a train standing at the eastern switch. If we take 4 inches as the maximal diameter of the luminous area of a signal lantern and take 600 ft as a conservative estimate of the distance of the stationary No. 2 (the value given at the trial for the distance from the station house to Hannah Reit's house[24]), then the visual angle subtended by the signal would be of the order of 2 minutes.

Holmgren's Triumph

During the trial, the conductor Martin and the baggagemaster Anderson were asked whether they were myopic (which they denied).[24] We can confirm the statement of Frey[21] that color deficiency is nowhere mentioned in the handwritten transcript of the trial—contrary to many suggestions in the secondary literature. Two months after the verdict, however, on 14 July 1876, Frithiof Holmgren (Fig. 8) gave to a medical congress in Gothenburg an account of the method of screening with the wool test that he had already developed before the Lagerlunda accident;[41] and by his account[26] the assembled Nordic physicians unanimously resolved that it was necessary to investigate the incidence of color deficiency among railroad staff.

The management of the *Statens Järnvägar*, led by General Director Troilius, were initially skeptical: No doubt they could readily recognize an ophthalmologist with a proprietary test to push. Holmgren quotes their response as follows: "If color-blindness really exists, it cannot, at any rate, be amongst the employés, or it would undoubtedly have been remarked; especially must this be the case amongst the engineers and conductors, as they rise from inferior grades, and consequently have amply proved their ability to distinguish signals."[26]

Fig. 8. A portrait of the ophthalmologist and physiologist Frithiof Holmgren (1831–1897), in the possession of the *Östgöta nation*, University of Uppsala. Photograph by the present authors.

Holmgren, however, gained permission to test all 266 individuals employed by his local railroad, the Uppsala-Gävle line, which was under private management. Thirteen color blind staff were identified, or 4.8%, and they included a station-master, an engineer, two conductors, and two *banvakter*.[26]

The management of the *Statens Järnvägar* were still skeptical after receiving letters from Holmgren on 25 September and 8 October 1876. But on 13 October, General Director Troilius himself came to see a demonstration that Holmgren had prepared. The demonstration took place at Uppsala in a large hall, which was fully darkened.[7–9,41] Troilius and his management colleagues were stationed half way along one side of the hall. Holmgren had arranged for two colorblind conductors to attend, one of whom he knew (from his screening of the Uppsala-Gävle railroad) to be a protanope, and the other a deuteranope. To heighten the theatre of the occasion, Holmgren had the conductors attend in uniform. The two conductors were stationed at opposite ends of the hall, and Holmgren supplied them with signal lanterns. They were instructed that when one signaled to the other, the second should respond with the same signal. General Director Troilius himself was invited to specify the signal for the first conductor. He chose white. The first conductor showed red, and the second answered with green. There was a long, intense silence in the hall. And then Holmgren said: "Now we have seen this, it is clear that if any accident occurs as a result of color blindness, there is no doubt about where the responsibility lies."[8,9,41]

Holmgren's *coup de theatre* was successful. Within three days (16 October 1876), the *Statens Järnvägar* issued an order requiring all railroad physicians to familiarize themselves with Holmgren's method of screening for color deficiency.[41] Soon F.C. Donders travelled from Holland to Uppsala to consult Holmgren on behalf of the Dutch railroad[20,57] (and this may have been the impetus for Donders's several subsequent contributions to color science[58]). Other European railroads made their own reforms. Already in 1877, the Smithsonian Institute arranged an English translation[26] of the French translation of Holmgren's original monograph.[27] And in Boston, the ophthalmologist B. Joy Jeffries wrote in 1878: "What Professor Holmgren has accomplished leaves no excuse for our American railroads in hesitating or refusing to thoroughly test all their employés for defects of color-perception, and dismissing those who are color-blind."[30]

Holmgren's Subterfuge: A Pack of Aces

Was Holmgren very lucky in his demonstration of 13 October 1876? Could the conductors equally well have given consistent responses? No. The demonstration was rigged, although not by bribing the conductors.

Holmgren's subterfuge was known to only a few at the time. It is mentioned in a footnote in an obituary of Holmgren written by Hjalmar Öhrvall and published in 1898 by the local medical journal in Uppsala,[41] but has remained largely unknown in the literature on color deficiency. The trick was crafty: One of the signal lanterns given to the conductors contained three red glasses of different densities; the other contained three green glasses of different densities. The conductors were deceived because they were accustomed to judging colors by their luminosities. Three other pieces of evidence corroborate Öhrvall's account.

Firstly, around 1970, the Uppsala historian Matt Bergmark interviewed Holmgren's son, Israel, who confirmed the story: "Just så berättade pappa att det gick till"[8] [That's just the way father said it was].

Secondly, a year or so after the demonstration, Holmgren published in the Uppsala medical journal[28] an account of how daltonians could be tested with multiple layers of colored glass. Show a 'red-blind' (i.e. a protanope) a single light green, Holmgren suggests, and he will call it green. If you add a second layer, he will say 'between red and green'—an expression only the color blind would use. Add another glass and he will say 'red'. A 'green-blind' gives responses, Holmgren claims, in the opposite sequence. (The modern reader may doubt the latter claim, but Holmgren was conceptually working with the early Helmholtzian model in which the long- and middle-wave receptors are well separated in their spectral sensitivity, and his light sources were dominated by long-wavelengths.) This method is not useful, he suggests, for general screening—where his wool test is more appropriate—but is "a control method for special cases, e.g., for railroad and naval personnel" and "can be used to convince superiors."

Thirdly, however, the most striking evidence is physical—for the lanterns that Holmgren prepared for his demonstration still exist. They are those shown in Fig. 3 and in Fig. 9A. They survive in the *Medicinhistoriska museet Uppsala,* an extensive collection of medical apparatus that is housed in a former hospital in the forest outside the city of Uppsala. The lanterns carry a dusty label stating that they were those used by Holmgren in his demonstration to Troilius. They are in good condition and do not appear to have seen railroad service. One lantern has three red glasses, the other, two green glasses and one yellow-green.

We have measured the transmission spectra of these glasses, and we plot them in Fig. 9B, together with typical 'official' glasses in use on the railroad. In Fig. 9C we plot the chromaticities that the two lamps would display to Holmgren's audience. We also show examples of protan and deutan confusion lines. In principle, the variations in the S-cone signal (i.e., variations in the vertical positions in the diagram) should have allowed the dichromats to distinguish the red signals from the green signals, and the green signals from one another and from white. But notice that the absolute value of the S-cone signal is very small (compare the chromaticity of the 'official' signal white of the oil lamp with an equal-energy white) and almost certainly—as Holmgren himself tells us—the guards were deceived by the large variation in the luminosities of the lights. Below the chromaticity plot (Fig. 9C) we show the calculated relative luminosities of each light for a protanopic and a deuteranopic eye.

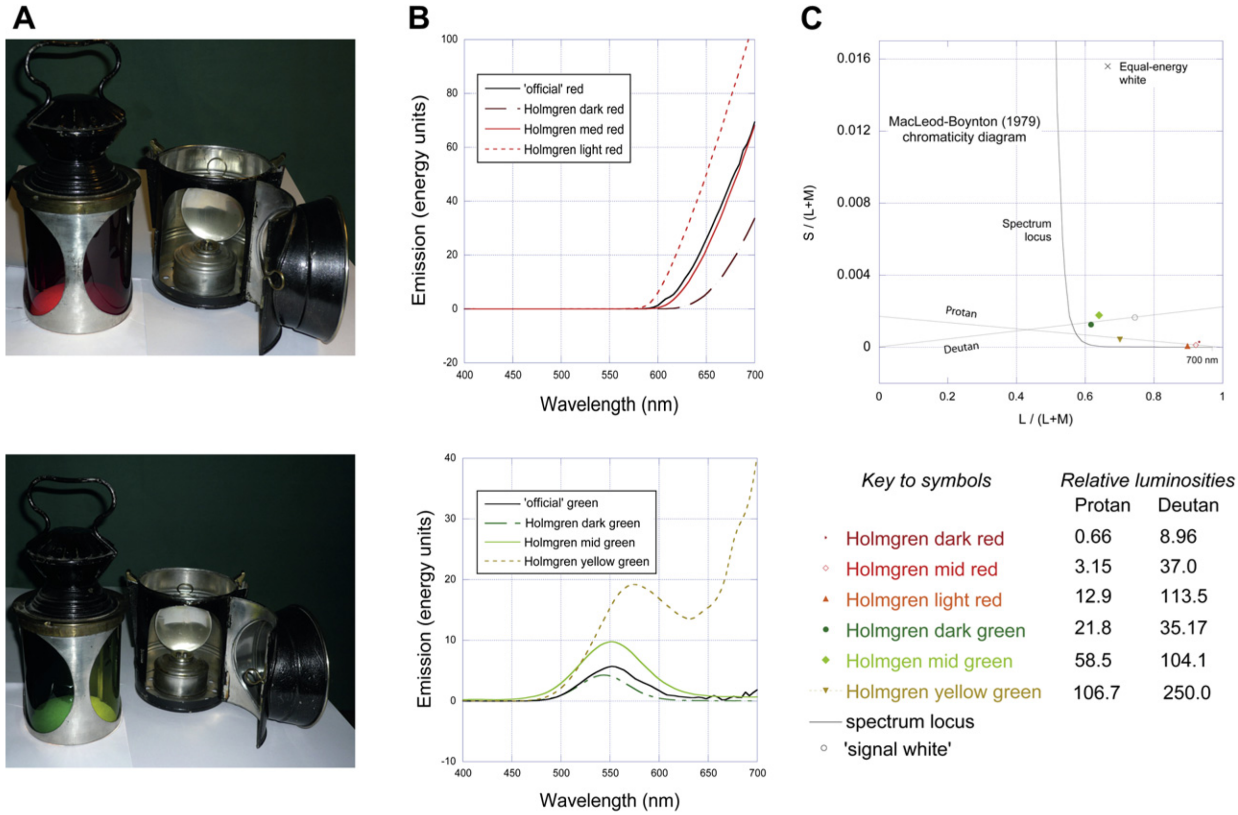


Fig. 9. *A*: The inner sleeves of the lanterns prepared by Holmgren for his demonstration to Troilius. These are the two lamps shown in Fig. 3. *B*: Output spectra from the two lamps, reconstructed from the emission spectrum of Fig. 7A and the measured transmission spectra of the glasses. *C*: The estimated chromaticity coordinates of the signals from each lamp, plotted in the MacLeod-Boynton diagram (see legend to Fig. 7). The curved solid line represents the chromaticities of monochromatic spectral lights (the 'spectrum locus'). Under this diagram we record the relative luminosities of the six lights as they would appear to protanopic and deuteranopic observers.

Conclusion

Without doubt the Lagerlunda accident had a central role in the introduction of screening for color deficiency by railroads throughout the world, but it is less certain that color deficiency had a central role in the Lagerlunda accident. The hypothesis remains plausible, and our measurements suggest that the signals in use would have been readily confused by daltonians; but there is no firm evidence that color deficiency did cause the collision, and we are confident that it was not the sole cause. We have catalogued the accumulation of errors that allowed an improbable accident come to pass.

Method of Literature Search

The term *Lagerlunda* was used to search ISI Web of Knowledge, PubMed, and the Database of 19th Century British Library Newspapers. Throughout our research, however, we have placed most weight on the primary sources referred to in the text.

Disclosure

The authors reported no proprietary or commercial interest in any product mentioned or concept discussed in this article.

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