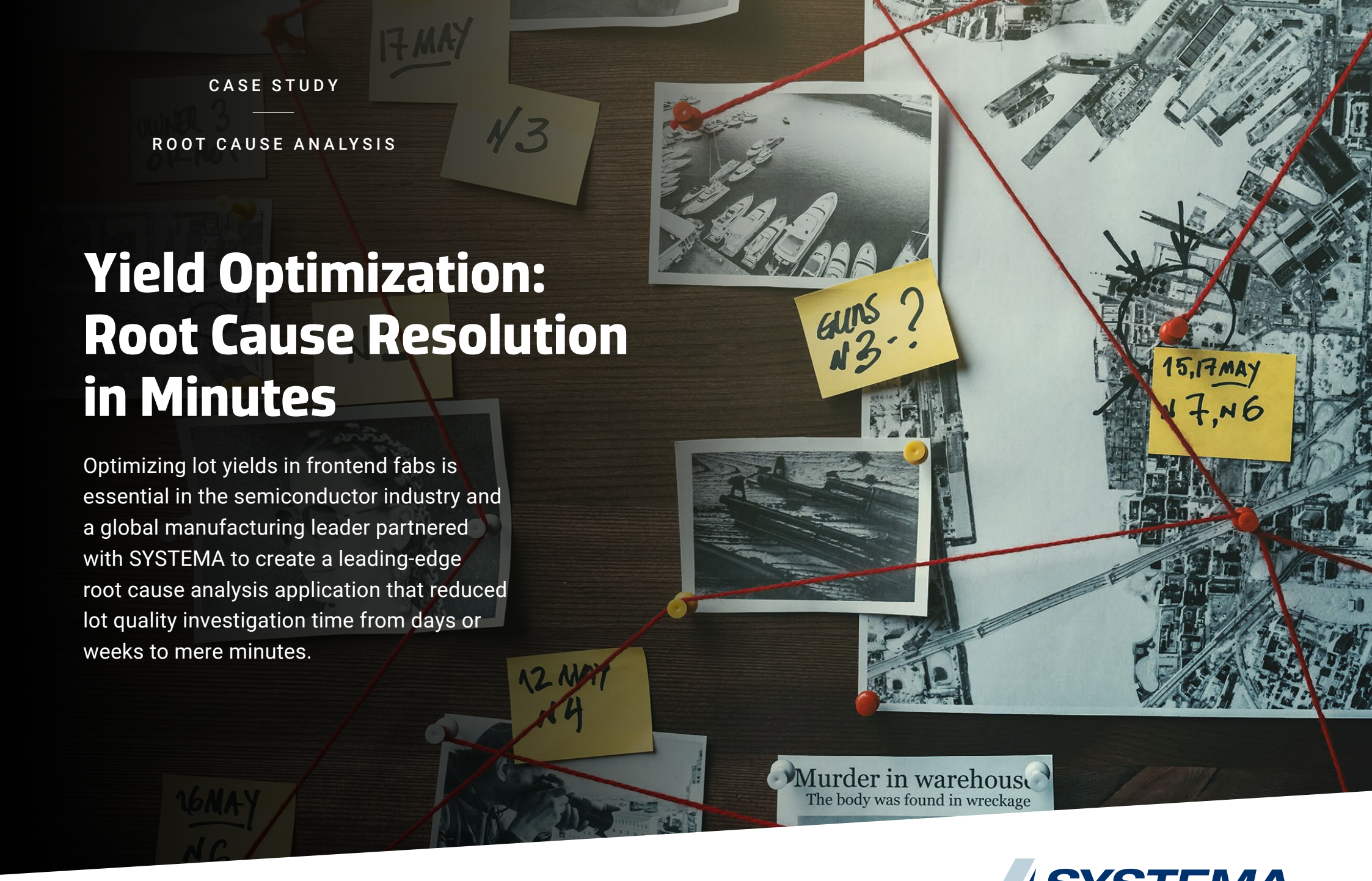
CASE STUDY

ROOT CAUSE ANALYSIS

Yield Optimization: Root Cause Resolution in Minutes

Optimizing lot yields in frontend fabs is essential in the semiconductor industry and a global manufacturing leader partnered with SYSTEMA to create a leading-edge root cause analysis application that reduced lot quality investigation time from days or weeks to mere minutes.



SYSTEMA
Art of Automation

Sherlock Holmes Would Surely Have Used This Tool for Investigations

In the ultra-competitive semiconductor industry, manufacturers are on a never-ending search for higher production yields that will deliver an edge, typically focused around lot quality, and the identification of those ever-elusive golden lots. Central to achieving this is the rapid and accurate discovery of root causes of lot quality issues. No easy task in a multi-trillion-dollar industry with a 70-year history. But a multi-billion-dollar global manufacturing leader with over 40,000 employees found a way with the help of cutting-edge technology and SYSTEMA.

They envisioned, and then created, an application with a Google Maps-like user interface that would track lot locations and movements over time in their semiconductor frontend fabs, along with maintenance and other events which might impact lot quality, and then they combined it with user-defined time period analysis so as to expedite root cause analysis of lot quality issues. The net result: an application that significantly reduced the time needed for root cause investigations of lot quality issues – often as much as from weeks or months down to just minutes.

Industry Challenge: Finding a Speck of Dust in a Haystack

The semiconductor industry is one of extremes. The number of devices manufactured is now measured in the sextillions. Semiconductor size is now measured in nanometers. A single manufacturing machine can cost millions. A single wafer can spend five weeks or longer in a front-end fab and travel so far that the distance is akin to circling the globe multiples times.

Producing at massive scale, and yet with extremely high quality and minimal defects, is the almost Utopian objective in the endless pursuit of the highest possible yield, where even a speck of dust settling on a wafer can lead to defects. Indeed, trying to identify what caused a lot quality issue in the last five weeks can feel like searching for a speck of dust in a haystack – all the old metaphors fall short because, while the data is available to discover root causes of lot defects, it is simply way too overwhelming to sift through all of it.

Sherlock Holmes would probably pass on this case because even his logical abilities could not handle the sheer volume of data: hundreds of machines and robots spread out over hectares of fab floor space, all intermingling with a myriad of sensitive chemical elements – all of which leads to the generation of massive amounts of data every microsecond.

But the Data Analysis team at this manufacturer, who were responsible for root cause investigations of lot issues, had a clear vision for a new application, which would be fronted by a two-dimensional Google Maps-like user interface of the fab floor space, showing lot movements during a user-defined time period. All based on an underlying foundation of a massive amount of data related not just to the lots themselves, but also, to other event data that might be the cause of lot defects, such as equipment maintenance, robot moves, construction periods, clean room alarms or errors, and so forth. An investigation tool that might not find that speck of dust, but would at least point to the right haystack, and ultimately reduce the time required to find the root cause of lot defects.

Addressing the Challenge in a Research Project with SYSTEMA

With the vision for this new application in mind, the Data Analysis team approached SYSTEMA in 2015 to help put the other pieces of the puzzle together. A logical choice because this manufacturer and SYSTEMA have a long history of productive collaboration. Additionally, such an application would need to be built upon the foundation of data generated by the manufacturing systems and processes, and SYSTEMA has particular expertise and experience in this area. So SYSTEMA was the perfect partner to undertake this endeavour.

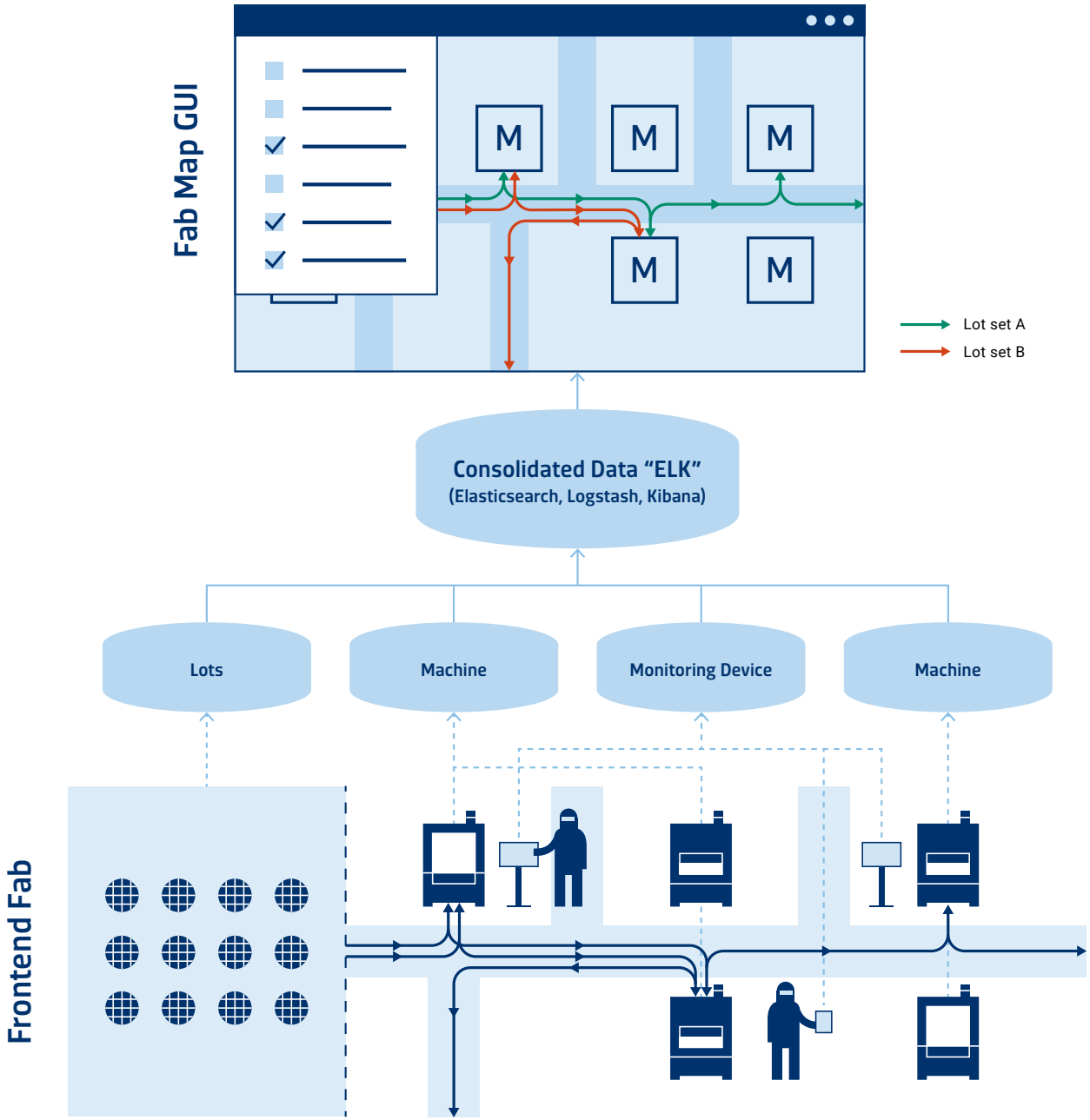
Funding for the project was provided by eRAMP and the research project to create this application was born, with the initial objective of rolling out the application in a single frontend fab in Germany.

The bad news was the same as the good news: there was a lot of data.

The IT Challenge: Crunch the Data, Map the Data, Search the Data

The good news at the start of the project: the data required to create such an application was available, in particular, historical lot position and movement data (including detailed geographical coordinates), which could be used to plot historical lot movements onto a two-dimensional map of the fab. So too was most of the data which would be required from each of the machines within the fab. Additionally, data from a wide variety of measuring systems and devices, as well as human-generated input data from process engineers and manual laborers, was also available and capturable.

The bad news was the same as the good news: there was a lot of data. But a lot of different data stored in heterogeneous systems, which was spread out across various data silos. So, an intensive harmonization and normalization effort was required to consolidate all of the required data into a single consolidated set of data that would serve as the back-end of the application. The challenge was particularly great when it came to the normalization of geographical coordinate data – where even a meter differential from the reality would result in an inaccurate visualization.



Next challenge: serve the massive quantity of data up to the Fab Map GUI. Historically, this would have been considered anywhere from problematic to impossible, but Elasticsearch technology had already proven itself by 2015 as the leading technology for solving such Big Data problems, so the ELK stack was chosen to implement the back-end of the application. ELK includes three components: Elasticsearch for ultra-fast data navigation and search, Logstash for data capture and preparation, and Kibana for data analysis and visualization. The full architecture is shown in *Figure 1*.

Quick search was particularly critical for delivering a satisfying user experience because while the two-dimensional map of the fab would be initially impressive, without the ability to quickly examine specific time periods, and to filter for specific data, the users would undoubtedly walk away while the computer was processing.

Figure 1: The application architecture, featuring the ELK stack in the middle, which serves the Consolidated Data up to the Fab Map GUI, including precise lot locations and movements, as in the example of Lot set A and Lot set B.

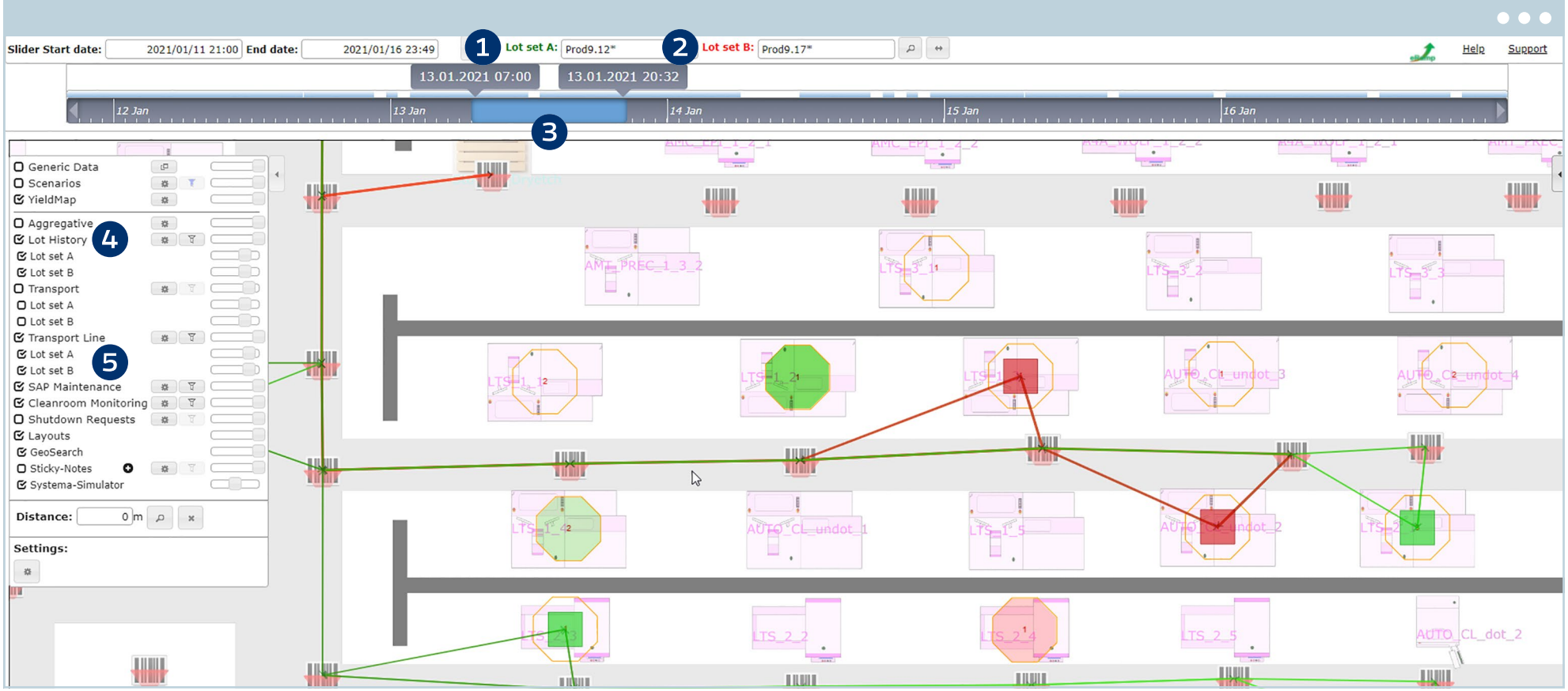


Figure 2: The Fab Map GUI can be completely customized to depict data based on specific lots, a defined time period, and various other settings.

The Solution: Comparing Two Lots and Identifying Quality Defects

Ultimately, the application was delivered to the Data Analysis team and it consisted of a variety of views all focused on the map of the fab floor space, and all supporting root cause investigations of lot quality issues, with a particular focus on the comparison of two different Lot sets to identify possible quality defects. The key elements of the screen are:

① Impacts on lot yields can easily be compared between Lot set A, depicted in green, and ② Lot set B, depicted in red, with the red indicating a lot set with less yield. Investigations typically start with a rough estimate of the time period that the event took place so ③ the slider at the top of the screen allows the Data Analysis team to narrow down the timeframe of what is depicted.

The selection panel on the left enables users to specify exactly what they want to see: in this example: ④ Lot History is selected for both Lot set A and Lot set B and ⑤ Transport Lines for both Lot set A and Lot set B are also selected. On the map, you can see the green lines showing the movement of Lot set A and the red lines showing the movement of Lot set B, during the time period specified.

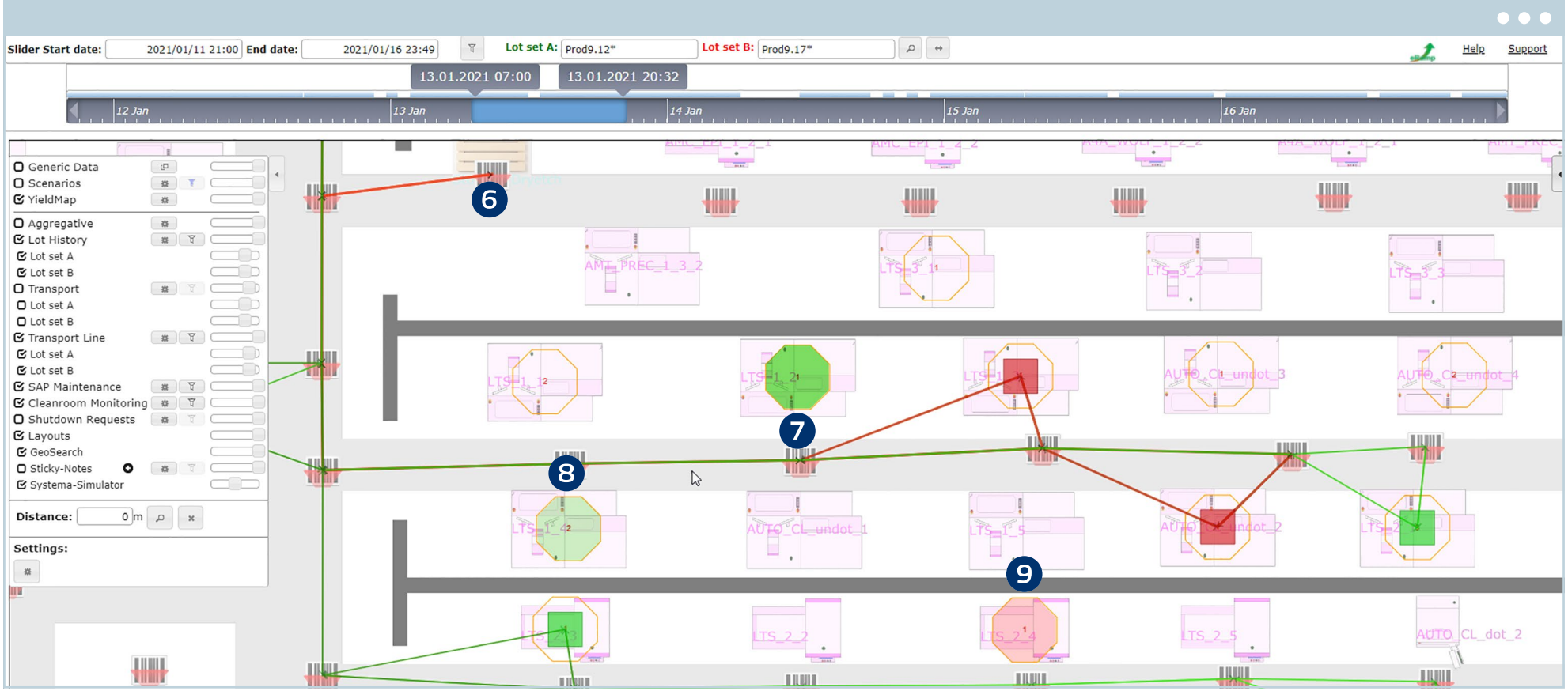


Figure 3: Lines indicate lot moves and arrows indicate the direction. Octagons identify maintenance events that may have impacted lot quality and the fill color of the octagon indicates which lot may have been impacted.

If you look closely, the arrow heads show the direction of the lot movement, as in the example at ⑥ where the arrow indicates a movement from left to right. More crucially in terms of quality analysis, octagons represent maintenance events that might have an impact on quality, and the fill color of an octagon indicates which lots may have been impacted. For example, the dark green octagon at ⑦ suggests that Lot set A may have been impacted by the maintenance event at this machine, and similarly, the light green octagon at ⑧ indicates there may have been slightly less impact on Lot set A, whereas, the pastel red at ⑨ indicates that the event may have impacted Lot set B.

Sherlock Holmes would surely smile at this and perhaps have taken the case after all if he had this application available.

A Huge Advantage: Root Cause Investigations are Reduced from Weeks or Months to Minutes

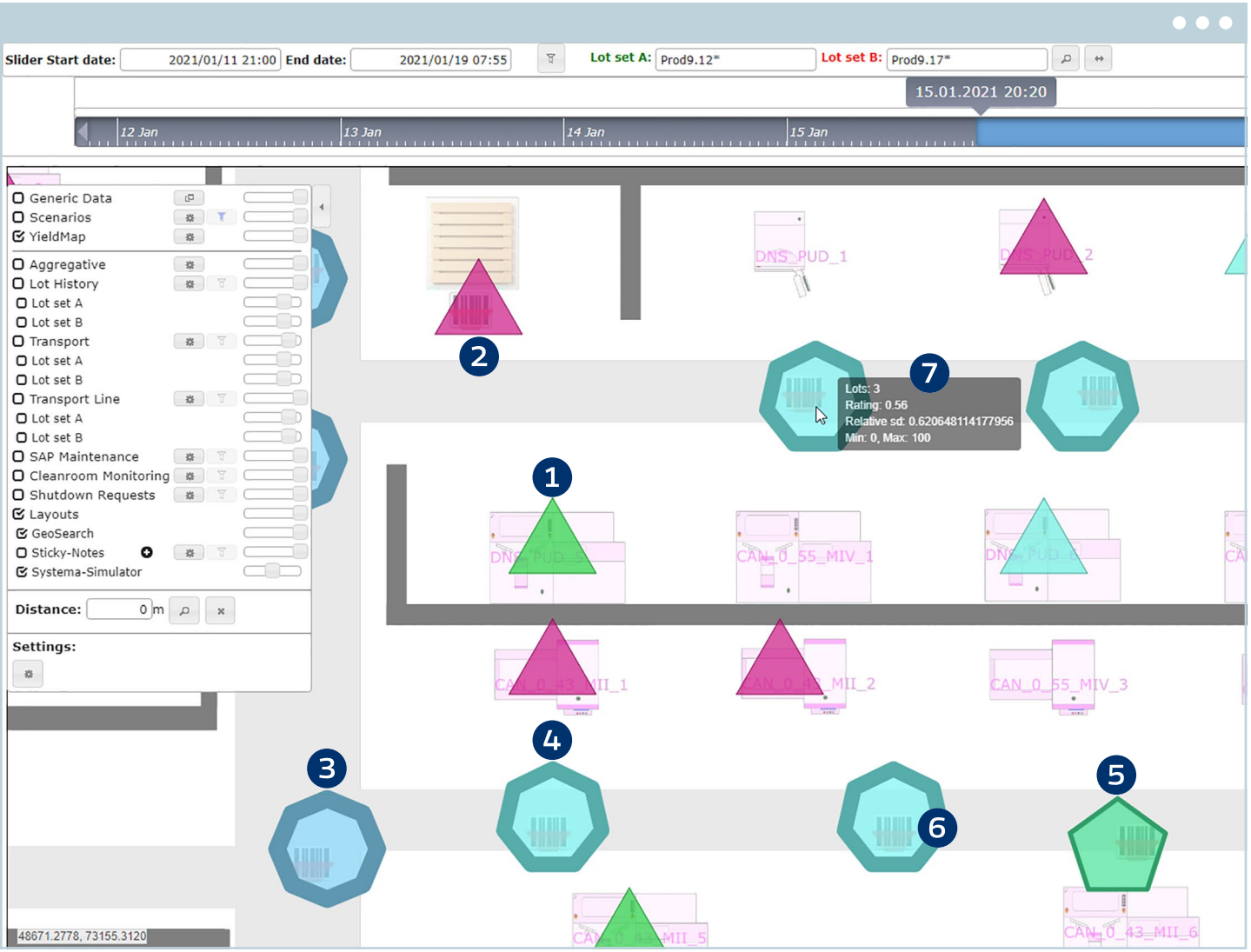
While the screen shown above is from a fictional simulation, the application quickly proved itself in the real world at one of the frontend fabs in Germany, where it was used to resolve a gas leak caused by an open valve that led to contamination of some lots. The time and location of the leak was generally known. So, the Data Analysis team started by specifying the general time period of the issue, and the general location on the fab map where it took place. The application then output all the details related to the contaminated lots so the team could take action right away.

The contaminated lots were quickly reworked and any significant production delays were avoided. It also ensured that no other tools or machines would be contaminated by the contaminated lots. A slew of other negative ramifications, primary among which would have been a contractual penalty being incurred (requiring a payment to the manufacturer's customer), were also avoided.

This investigation may have taken weeks or months in the past, but the application enabled the Data Analysis team to pinpoint all contaminated lots in significantly less time. To the point where root cause investigations can now be solved in minutes rather than weeks or months. But the use cases don't stop at just identifying lot contamination. A wide variety of other use cases are possible, not the least of which is proactively using the application to differentiate the good lots from the very good lots, that is, to identify the golden lots. It's all about the yield so a Yield Map was added to support this exact use case...

Root cause investigations can now be solved in minutes rather than weeks or months.

Figure 4: The Fab Map GUI can also display Yield Map information with lot volumes and lot quality immediately identifiable based on the shapes and colors.



Finding those Golden Lots: Assessing Quality with a Yield Map

To facilitate the identification of golden lots, and more generally to look at quality factors and how they impact yield, the application was expanded to include a Yield Map, which displays a geographical representation of lot quality information *(Figure 4)*.

Key features of the Fab Map GUI are: ① Triangles indicate lower lot volumes, whereas octagons represent significant lot volumes, with the quality of lots indicated by the fill color of a shape, for example at ② the pink being on the low end of the quality spectrum ③ purple and ④ turquoise being the middle range and ⑤ green being the high end. ⑥ The border thickness of the geometrical shapes depicts the value of the standard deviation from predefined quality metrics. ⑦ The info box at the mouse pointer shows more detailed information related to the relative standard deviation (sd) of the turquoise heptagon, roughly 0.62 % in this example.

So another tool in the Data Analysis team's arsenal. But they didn't stop there. They kept their investigative caps on and added more functionality…

Investigating the Scene of the Crime

Every investigation revolves around the scene of the crime. All of the clues are typically lying somewhere nearby – perhaps within 10 meters or so. Particularly true when it comes to lot defects, where even being close to a contamination incident can result in contamination of a lot.

Therefore, another powerful feature was added to the application: Distance Search. The user simply specifies a distance from a particular machine, such as in *Figure 5* where at ① a distance of 10 meters is specified which can be investigated for Lot set A and Lot set B. ② The 10 meter radius is indicated by the large blue circle, and ③ the light blue box in the lower-right identifies that there was indeed an issue within 10 meters that may have caused a defect. ④ The purple lines show the borders of areas with events that might impact quality, such as climactic violations.

Not quite the speck of dust in the haystack, but at least the Data Analysis team now knows which haystack to start their search in.

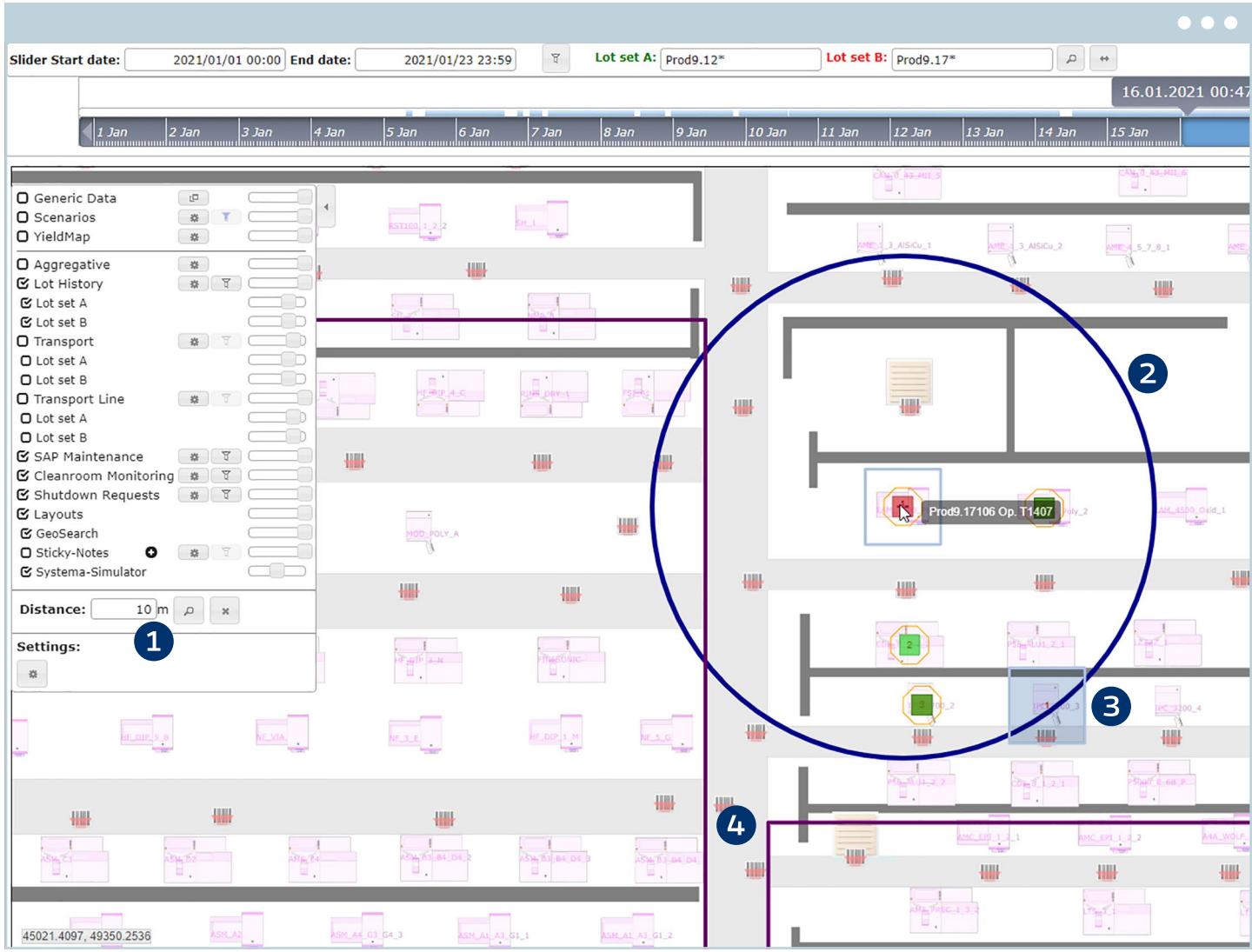


Figure 5: Distance Search can be superimposed on the Fab Map GUI to show any significant events that might have impacted lot quality, which took place within a 10-meter radius.

Expanding the Rollout and Chasing that Elusive Speck of Dust

Having proved itself in the first fab, the application was rolled out to three more fabs on two continents. Every fab layout is unique, and each one has its own set of heterogeneous data, so some effort was required at each fab, in particular to harmonize all of the data and to define the two-dimensional map of the fab. But some short-term pain for significant long-term gain proved worthwhile, and now in 2021, the manufacturer may also roll out to additional fabs.

As for the future, the application functionality is being iteratively increased, primarily by adding new underlying data, to broaden the scope of potential root cause discovery. For example, train schedules for tracks nearby to the fab are being incorporated into the consolidated data because train vibrations are yet another factor that may contribute to defects. With nanometer size wafers, even a degree here and there of heat or cold can be damaging so, further into the future, the consolidated data will be expanded to include seasonal temperature and humidity fluctuations.

Indeed, the sky is the limit because the consolidated data along with the user-friendly fab map, can serve as the steppingstone to a multitude of additional functionality, including not just post-mortem investigations, but more immediate and proactive analysis, and in turn, help with the elimination of inefficiencies. Add to this machine learning based on the huge set of available data and the possibilities are very exciting.

Moreover, in an industry that enables almost every electronic device on the planet, the need for greater quality and yield consistently goes up, but the opportunities for delivering greater yield and quality go down. With this new application, the manufacturer has further consolidated its reputation as a global leader by creating a powerful tool in their search for ultimate quality. It has also been an exciting journey for SYSTEMA to support the manufacturer along the way and help with the realization of a critical differentiator based on technology.

Questions about SYSTEMA's Root Cause Analysis?
Please feel free to ask a specialist at contact@systema.com
or read more about this topic on the web at:

systema.com/advanced-manufacturing-intelligence

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