ViDX: Visual Diagnostics of Assembly Line Performance in Smart Factories

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Bosch Research North America, Zhejiang University. 2016

Cybersyn, Chile 1971–1973

Distributed decision support system designed by British operations scientist Stafford Beer.

- An operations room,
- Economic simulator,
- Custom software to check factory performance,
- Using national network of telex.

Cybersyn opsroom image credit Gui Bonsiepe

SCADA: Supervisory control and data acquisition

- Industrial processes

Manufacturing, Process control, power generation, fabrication.

- Infrastructure processes

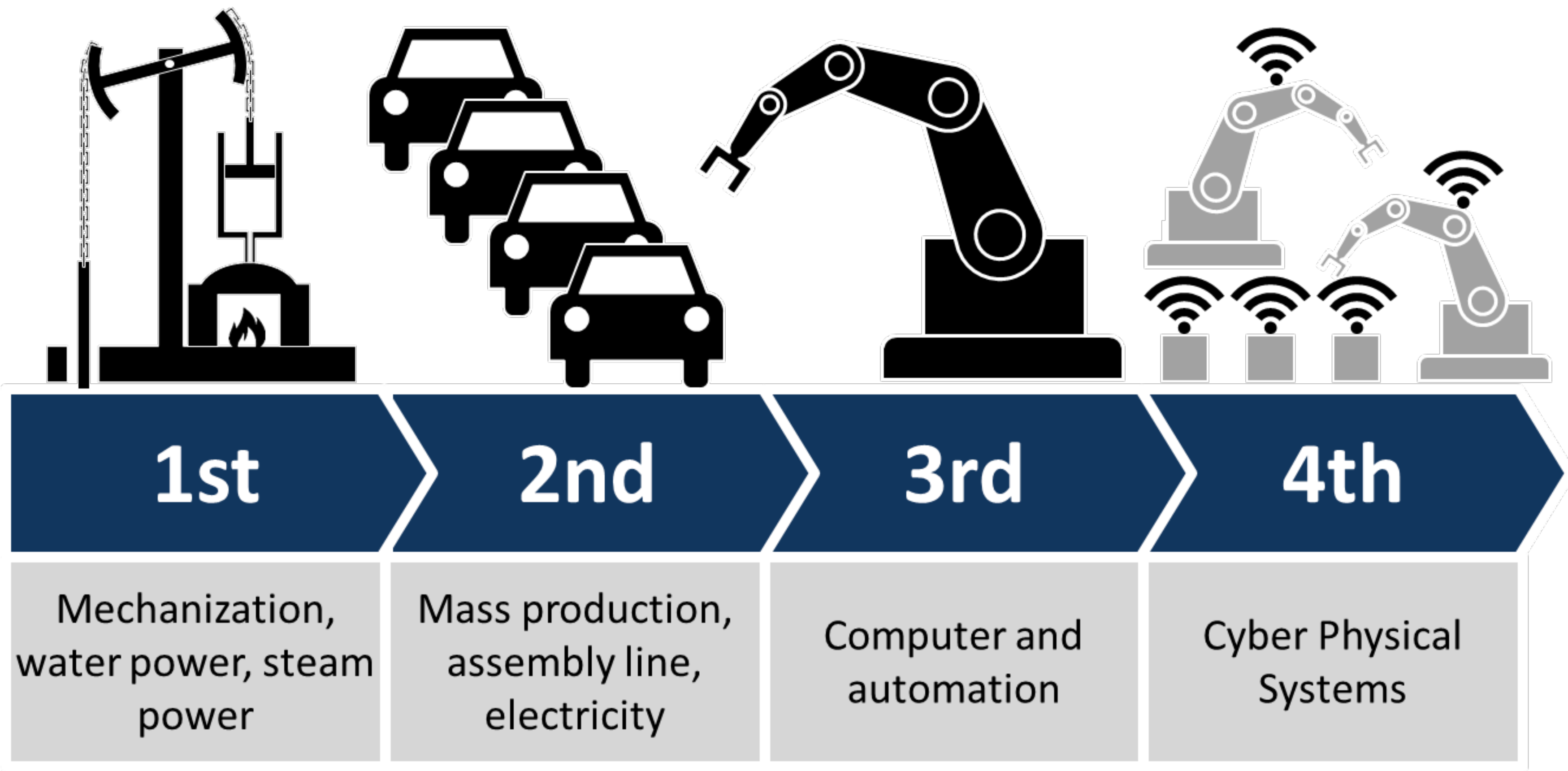
Oil and gas pipelines, electrical power transmission ,water treatment.

- Facility processes

Monitor and control heating, ventilation air conditioning systems (HVAC),and energy consumption.

http://www.promotic.eu

Industry 4.0



credit "*Christoph Roser at http://www.allaboutlean.com*

Every second matters!

Cisco $1594 per second

Samsung $1540 per second

1 year = 525,600 minute

Nokia $941 per second

Ford — Kansas City Assembly Plant, Claycomo, MO

460,338 cars per year

Hyundai — Hyundai Motor Manufacturing Alabama, Montgomery, AL

342,162 cars per year

Nissan — Nissan North America, Smyrna, TN

333,392 cars per year

http://www.automobilemag.com/
www.businessinsider.com/visualizing-how-much-big-tech-companies-make-2014-4

Why performance monitoring?

- TPM:Temporal productive maintenance

- OEE: Overall equipment effectiveness

Category	OEE Loss	Example
Breakdowns	Availability	- Tooling failures - General breakdown - Unplanned maintenance - Equipment failure
Setup Adjustment	Availability	- Material shortages - Setup / Changeovers
Small Stop	Performance	- Cleaning / Checking - Obstructed Product Flow / Component Jams - Misfeeds - Sensor Blocked / Delivery Blocked
Reduced Speed	Performance	- Operator inefficiency - Rough running / Equipment wear - Under nameplate capacity / under design capacity
Startup Rejects	Quality	- Incorrect Assembly - Scrap / Rework - In-Process Damage / In-Process Expiration
Production Rejects	Quality	- Scrap / Rework - In-Process Damage / In-Process Expiration - Incorrect Assembly

Gantt chart

Gantt charts illustrate the start and finish dates of the terminal elements and summary elements of a project.

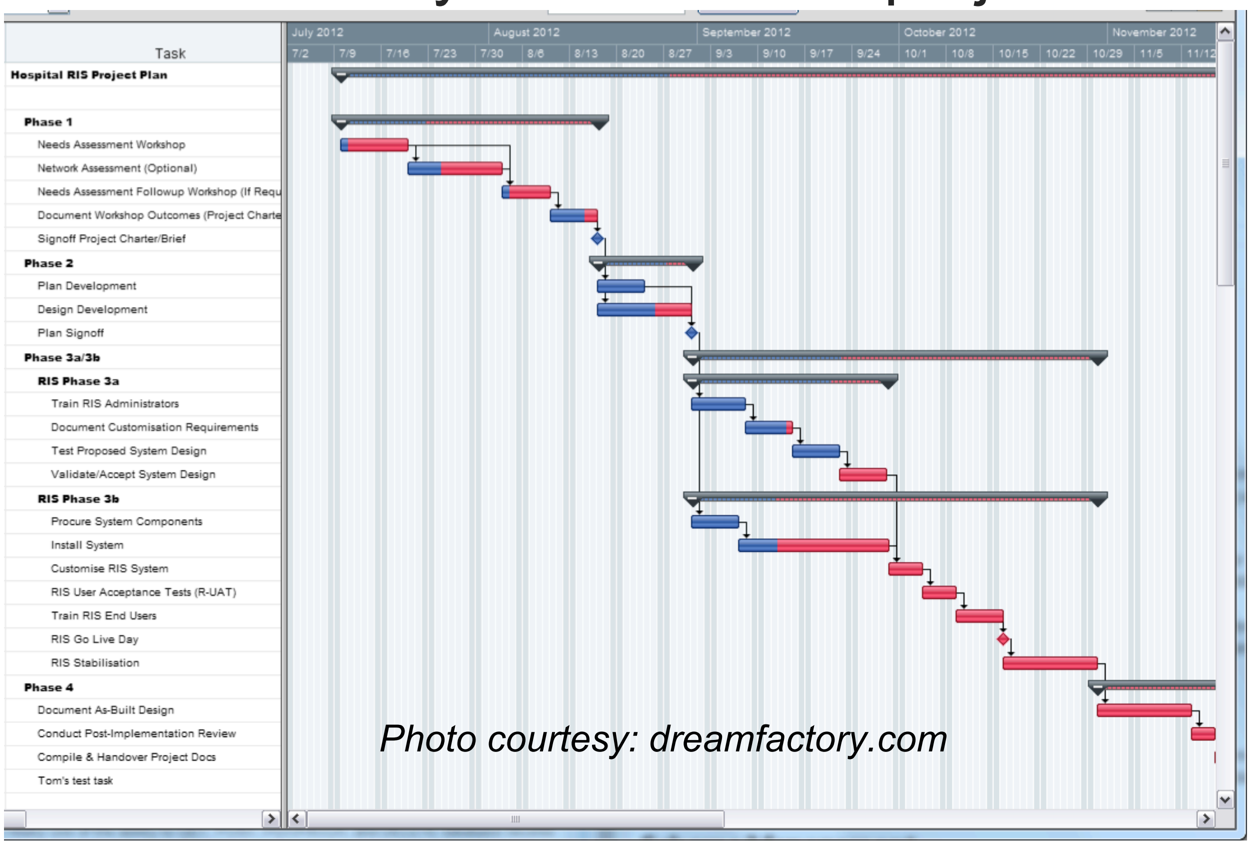


Photo courtesy: dreamfactory.com

Contribution of ViDX

Visual exploration for :

- Troubleshooting
- Process optimization
- Decision making

Identify inefficiencies and locate abnormalities in:

- Historical data.
- Realtime assembly line performance.

Requirements gathered through discussion with **Managers** and **Operators?**

REQUIREMENTS FOR HISTORICAL DATA

R1: Facilitate the detection of abnormal processes.

R2: Inefficiencies and troubleshooting.

R3: Engaging users to detect outlier process interactively.

R4: Support predictive analysis.

REQUIREMENTS FOR REAL-TIME SYSTEM

R5: Highlight abnormalities in real time.

R6: Visual metaphors.

R7: Interactive exploration of large amount of process data (thousands of products everyday).

R8: Visually indicating the problematic components in 3D model!!

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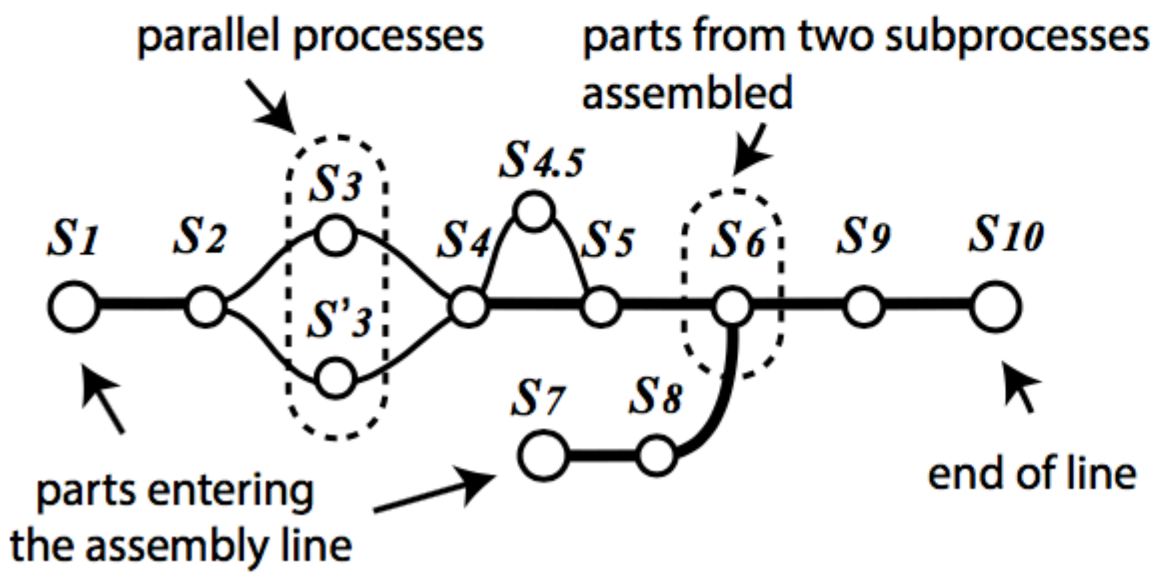
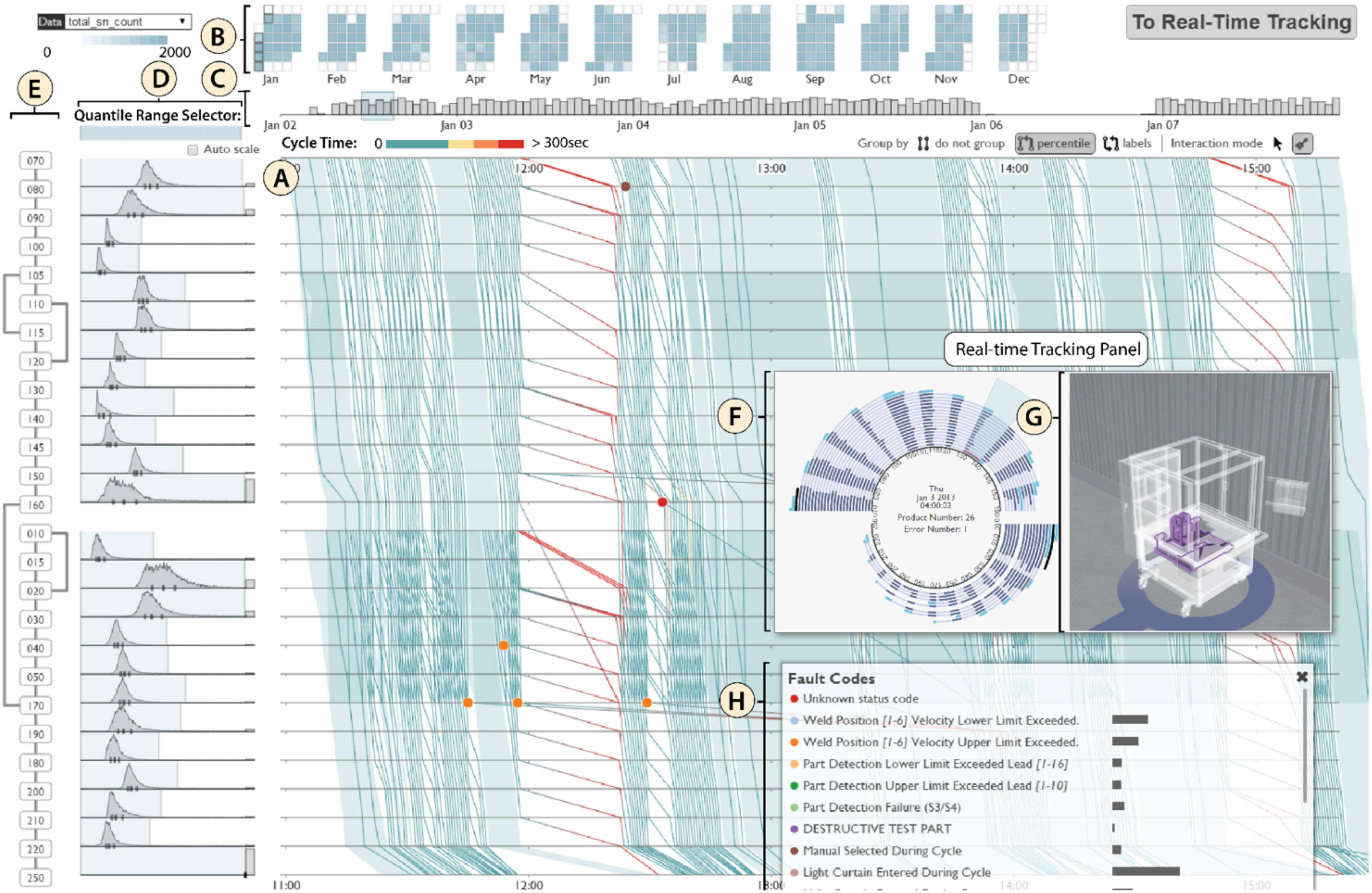
Assembly line as a directed acyclic graph (DAG)



No error! Quality Control!
How about repeating operations

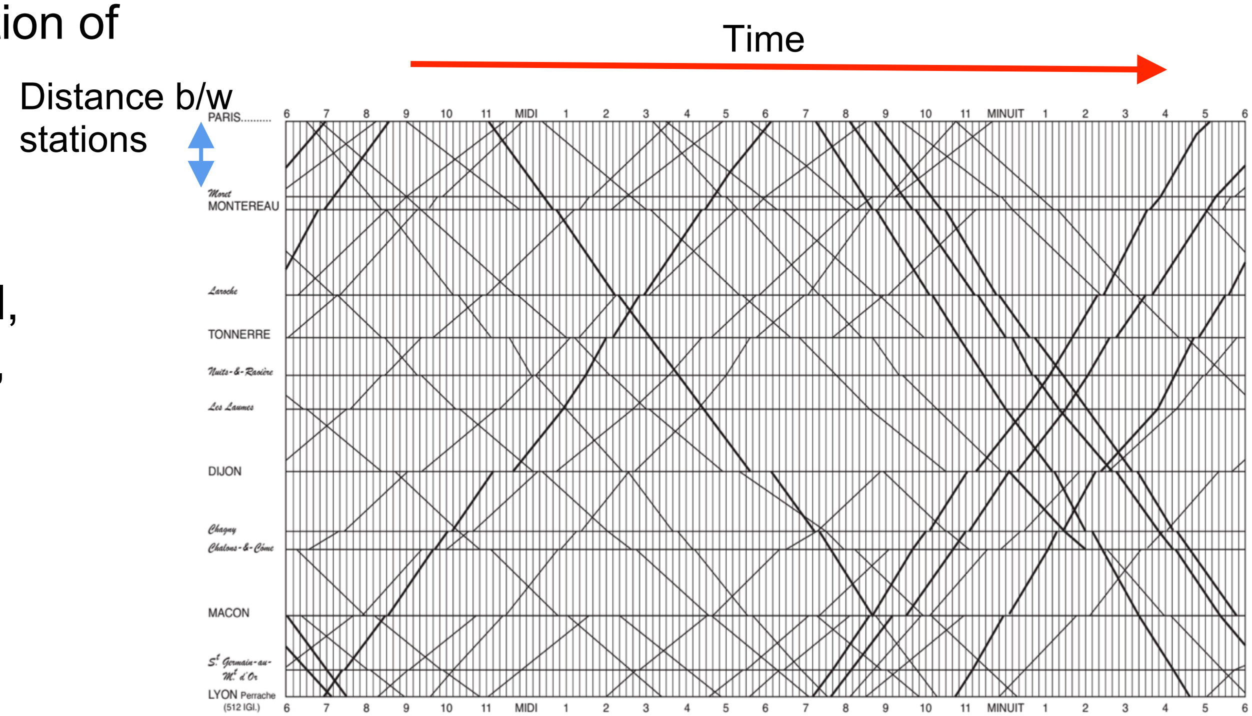


To Real-Time Tracking
Data total_sn_count
0
2000
A
B
C
D
E
F
G
H
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Quantile Range Selector:
Auto scale
Jan 02
Jan 03
Jan 04
Jan 05
Jan 06
Jan 07
Cycle Time: 0
> 300sec
Group by
do not group
percentile
labels
Interaction mode
12:00
13:00
14:00
15:00
11:00
Real-time Tracking Panel
Thu
Jan 3 2013
04:00:02
Product Number: 26
Error Number: 1
Fault Codes
Unknown status code
Weld Position [1-6] Velocity Lower Limit Exceeded.
Weld Position [1-6] Velocity Upper Limit Exceeded.
Part Detection Lower Limit Exceeded Lead [1-16]
Part Detection Upper Limit Exceeded Lead [1-10]
Part Detection Failure (S3/S4)
DESTRUCTIVE TEST PART
Manual Selected During Cycle
Light Curtain Entered During Cycle
070
080
090
100
105
110
115
120
130
140
145
150
160
010
015
020
030
040
050
170
190
180
200
210
220
250

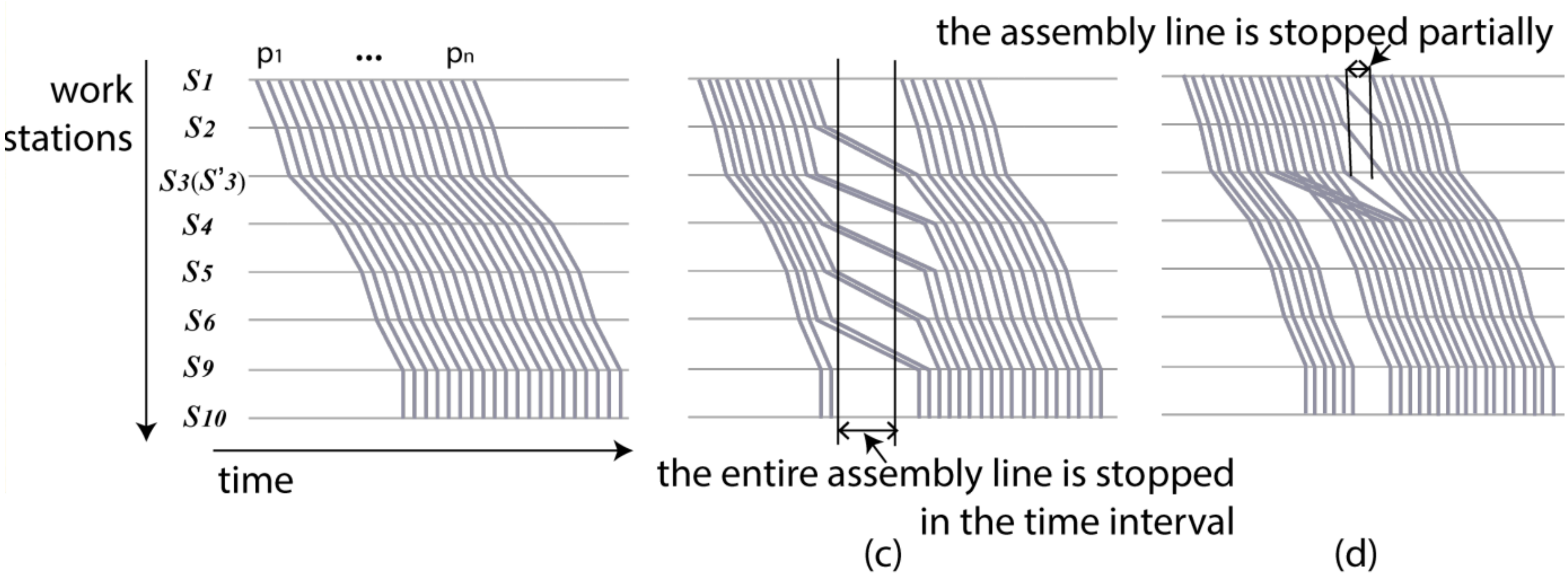
Extended Marey's graph

1885 as a visual depiction of train schedules.

- Train speeds,
- Dwell times,
- Directions of travel,
- Service frequency,
- Stop spacing



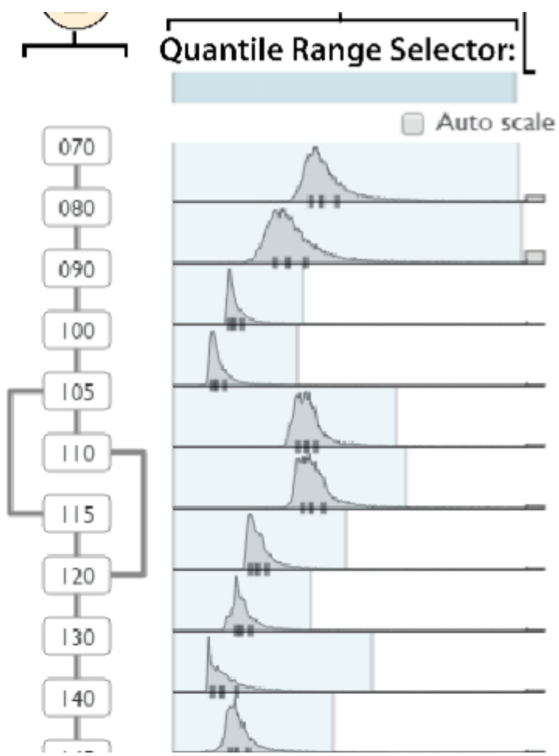
Anomaly detection

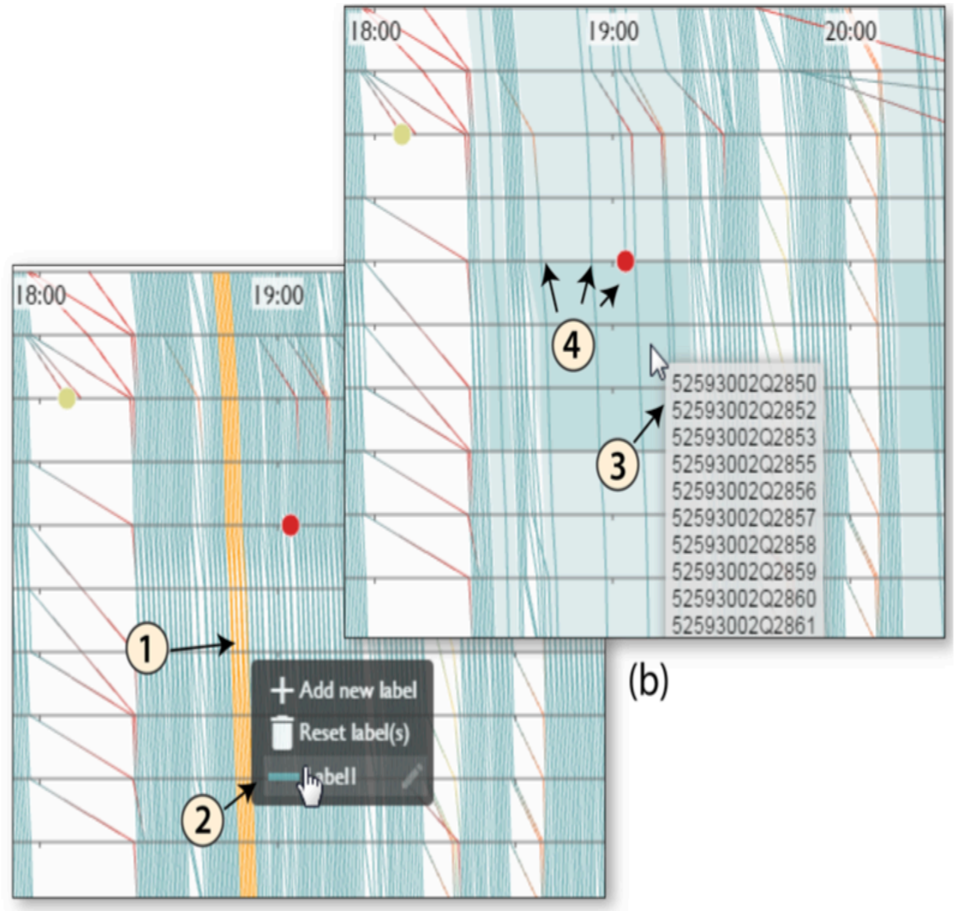


1. Steak of efficient process
2. Halt of entire assembly line
3. Partial halt of assembly line

Quantiles brush and Sample brush

Interactive outlier detection

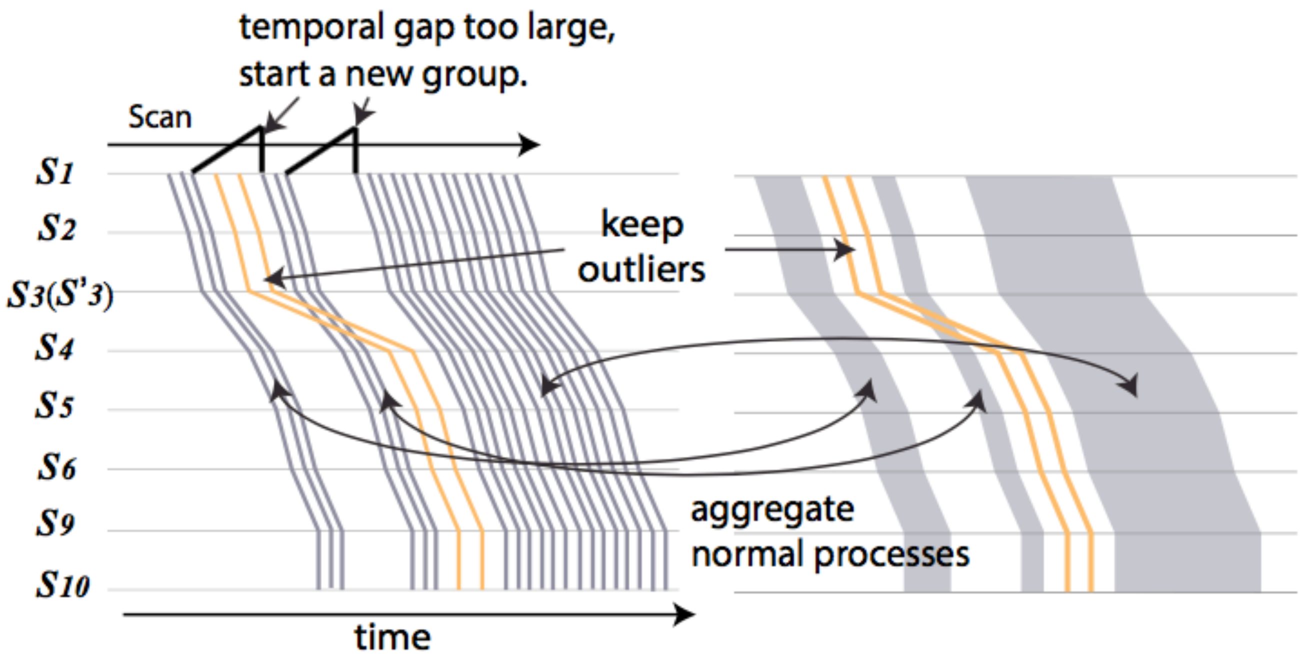




(b)

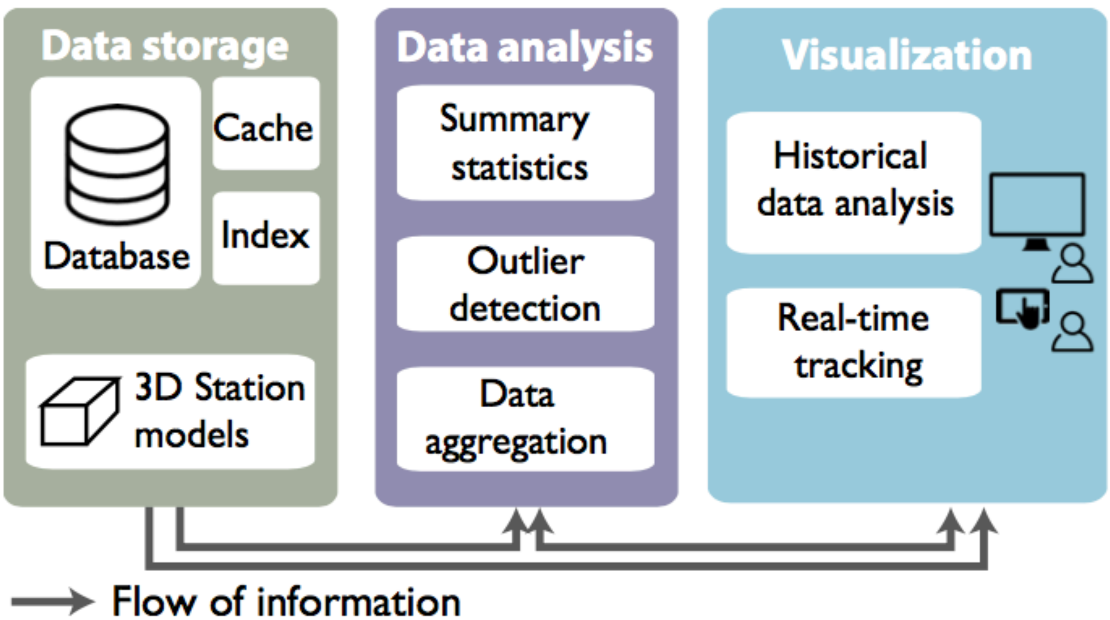
(a)

Aggregation



Visualizing larger number of processes in parallel coordinates [Munzner, Tamara. *Visualization analysis and design*. CRC Press, 2014.pp 165]

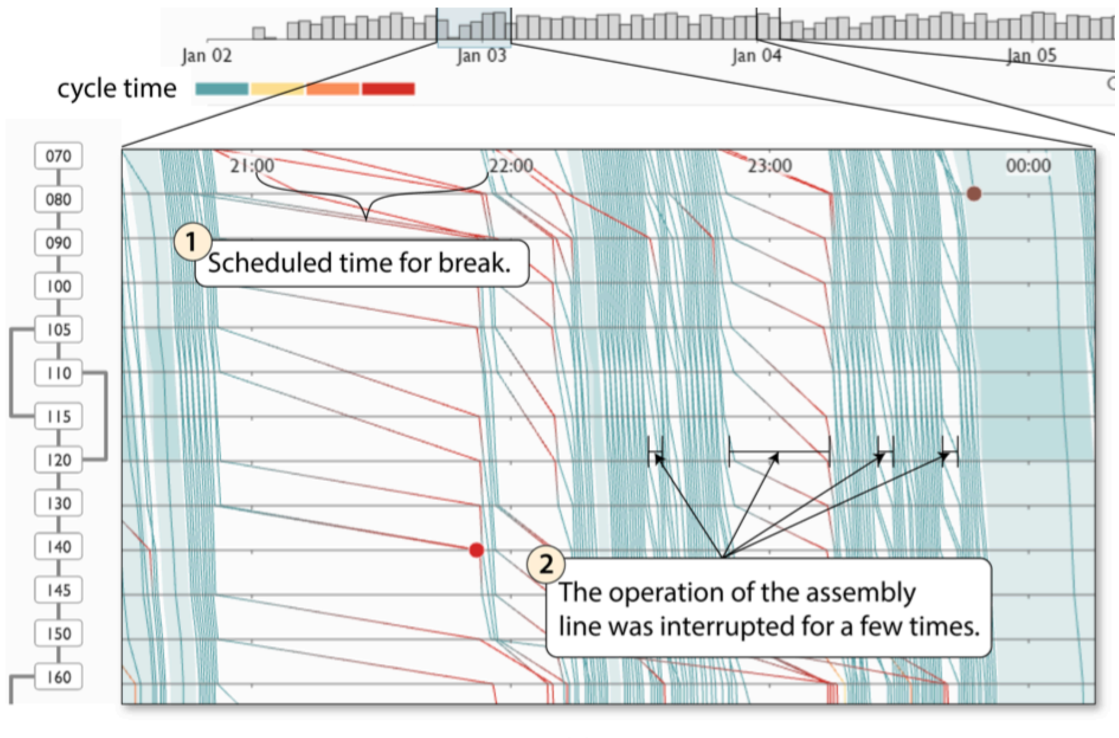
System architecture and implementation



Case study

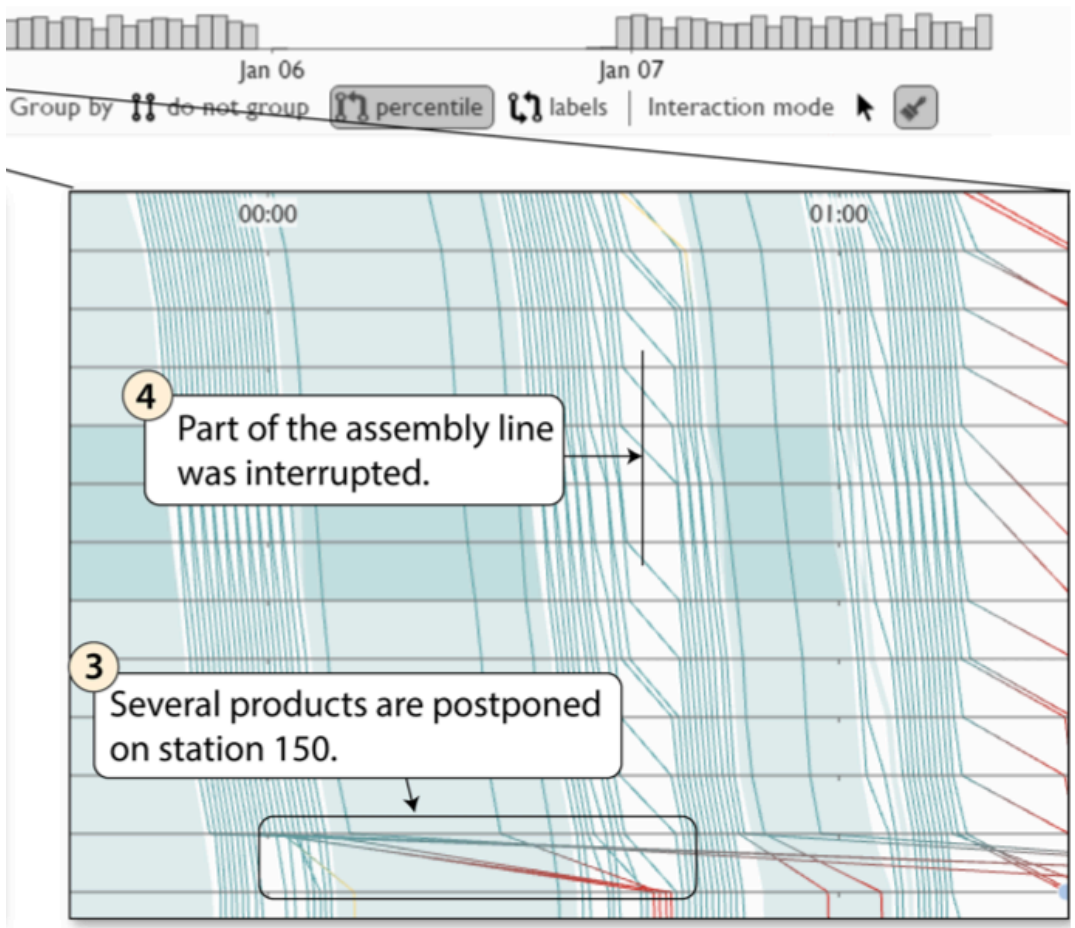
Detect inefficiencies and troubleshooting.

- Schedule break.
- Stop and restart for a few times before operating smoothly.

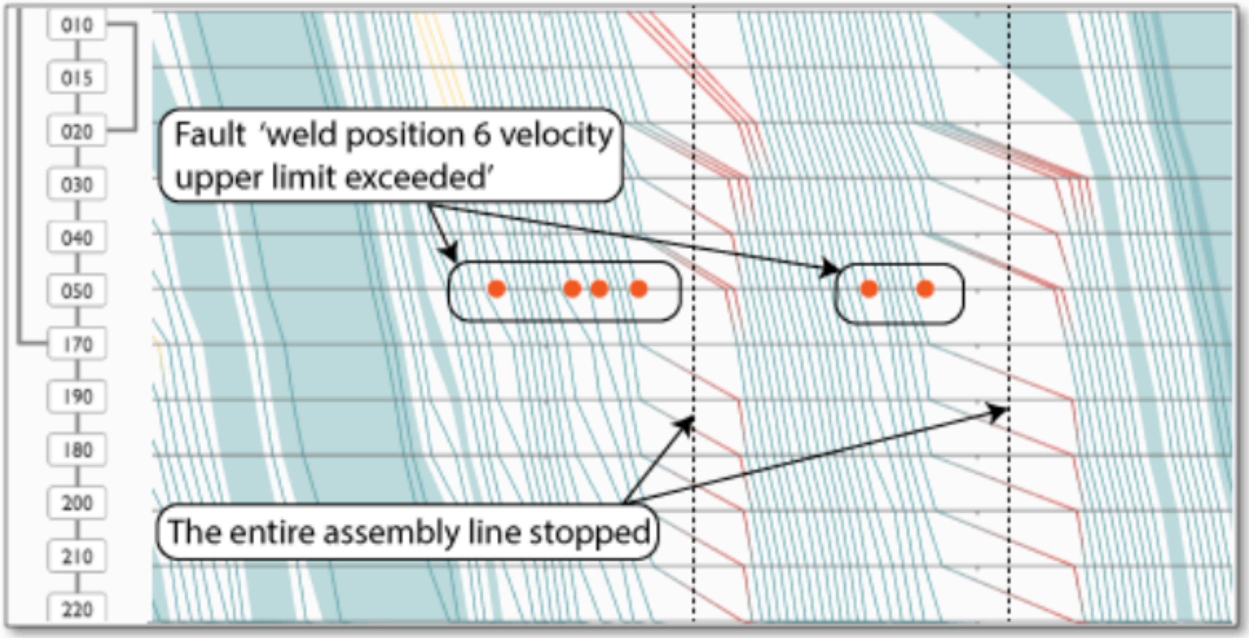


Case study

- Several products were postponed.
- Other products have to wait.



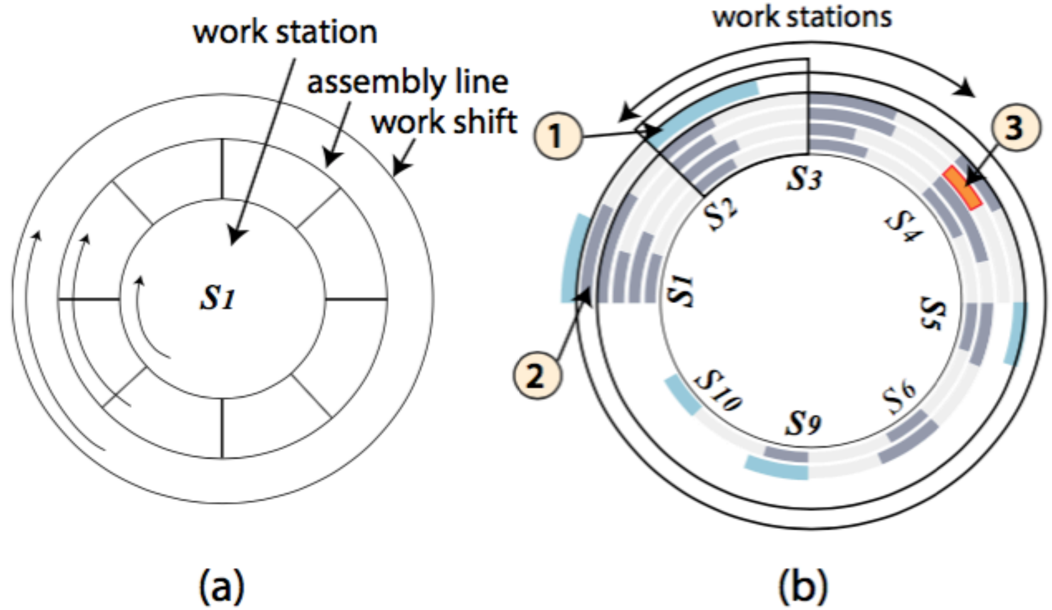
Fault detection

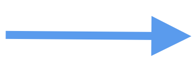


Real-time monitoring

Radial graph proposed by target users.

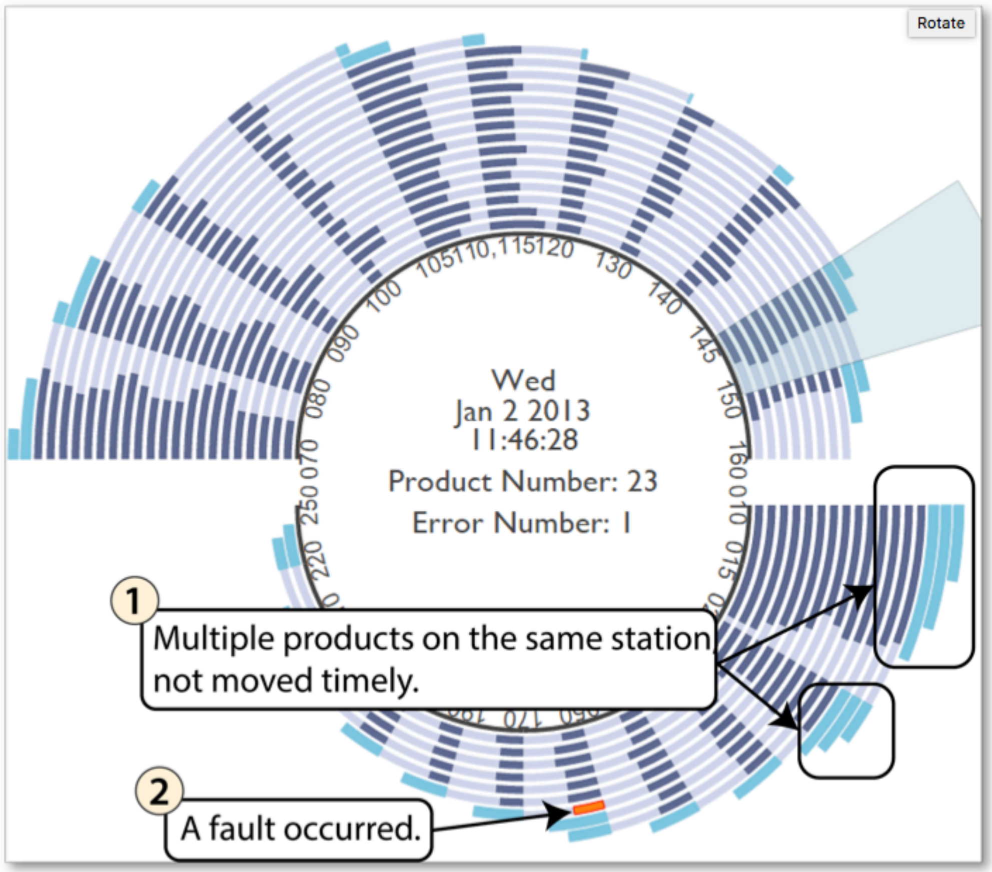
Users asked for three layers of rotating concentric circles.
Not effective

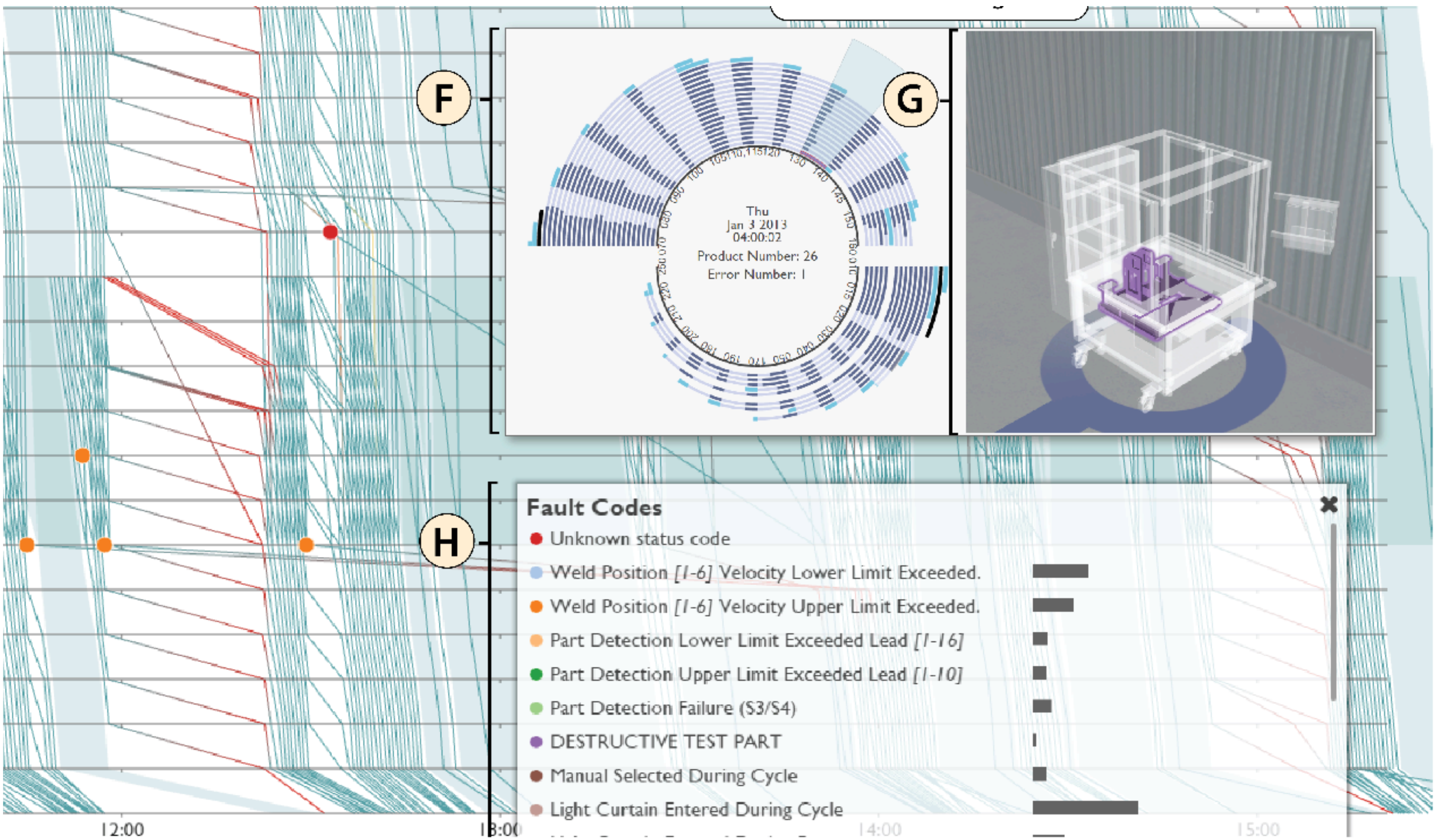


 **New design**

1. Ongoing process (light blue)
2. Length encode the time to finish the process
3. Fault occurs

Real time performance with radial graph





F
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12:00
13:00
14:00
15:00

What: Data	• Table of workstations and product information: many value attributes. E.g Serial time values, Error and workstation's DAG.
Why: Task	• Find trends, outliers, extreme, exploration and anomaly detection.
How : Encode	• Marey's graph and parallel layouts: horizontal spatial position used to express time on each station. Vertical traces shows the products. • Radial layout: Line length.
How: Reduce	• Item aggregation. • Filtering.
Scale	Dozens along vertical axis (Workstations) and thousands to millions?! polylines (products).

Limitations

- Data scalability:

    Site managers are willing to immediately know the abnormalities in each day in calendar visualization

- Longer time span in Marey’s graph:

    In displays with limited width, traces will become vertical lines

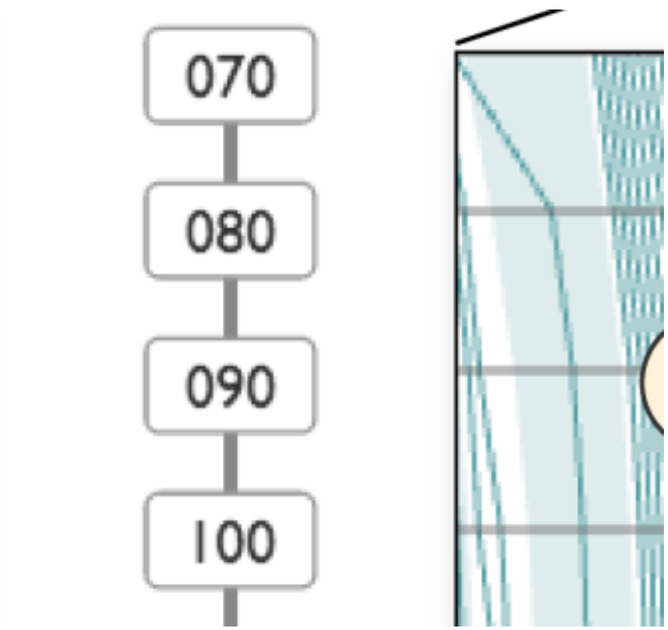
- Subprocess and parallel processes are overlaid

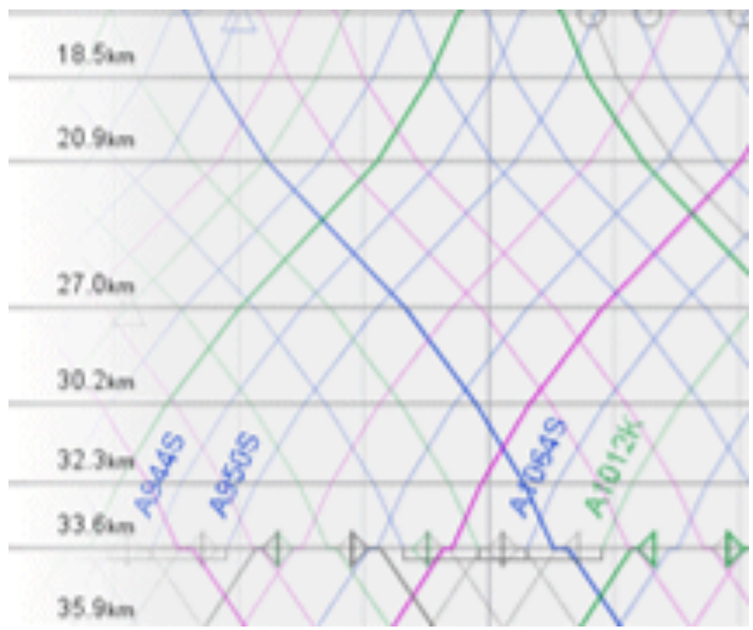
    Increasing the complexity of manufacturing process can cause visual clutter.

Suggestion

User can change the distance between stations based on average process time.

- Comparing lines with different length and slope (tilt).

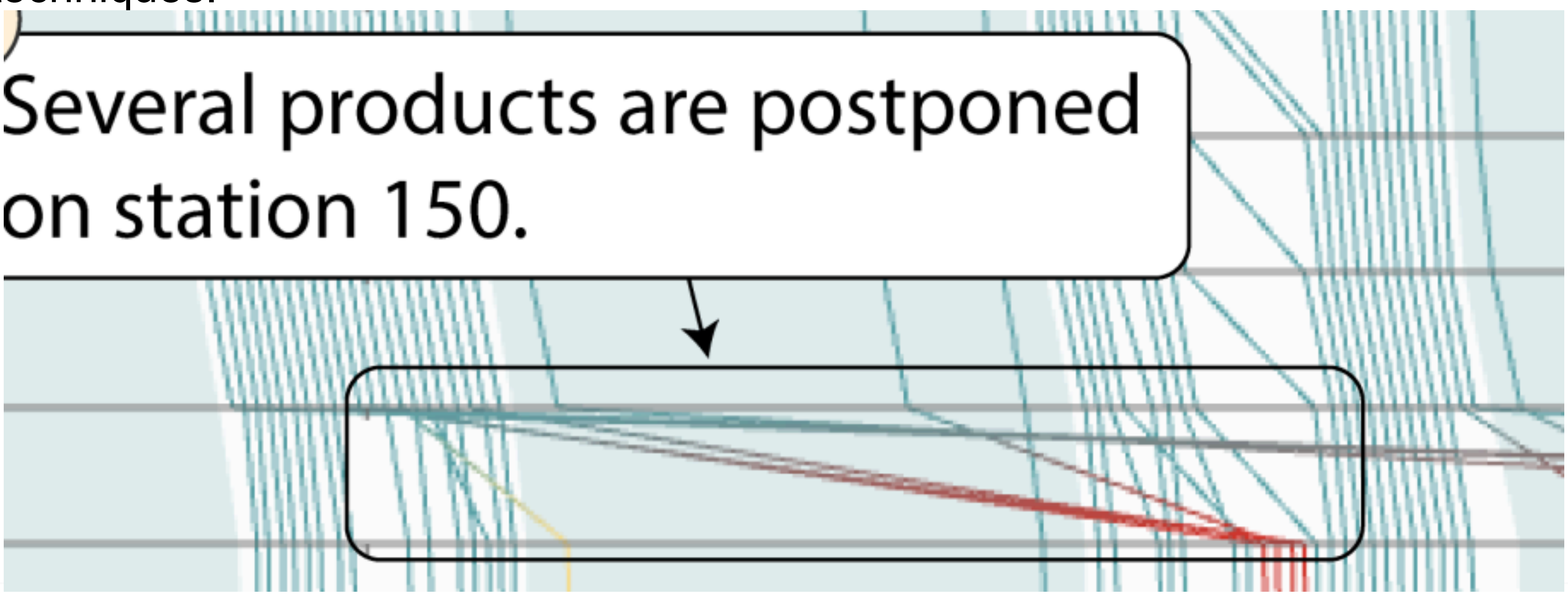




Critiques

❖ Every operation is trackable not every product.

There is no jump in production line and product will be stored in case of failure. FIFO system can cause overall delay and disables abnormalities detection techniques.



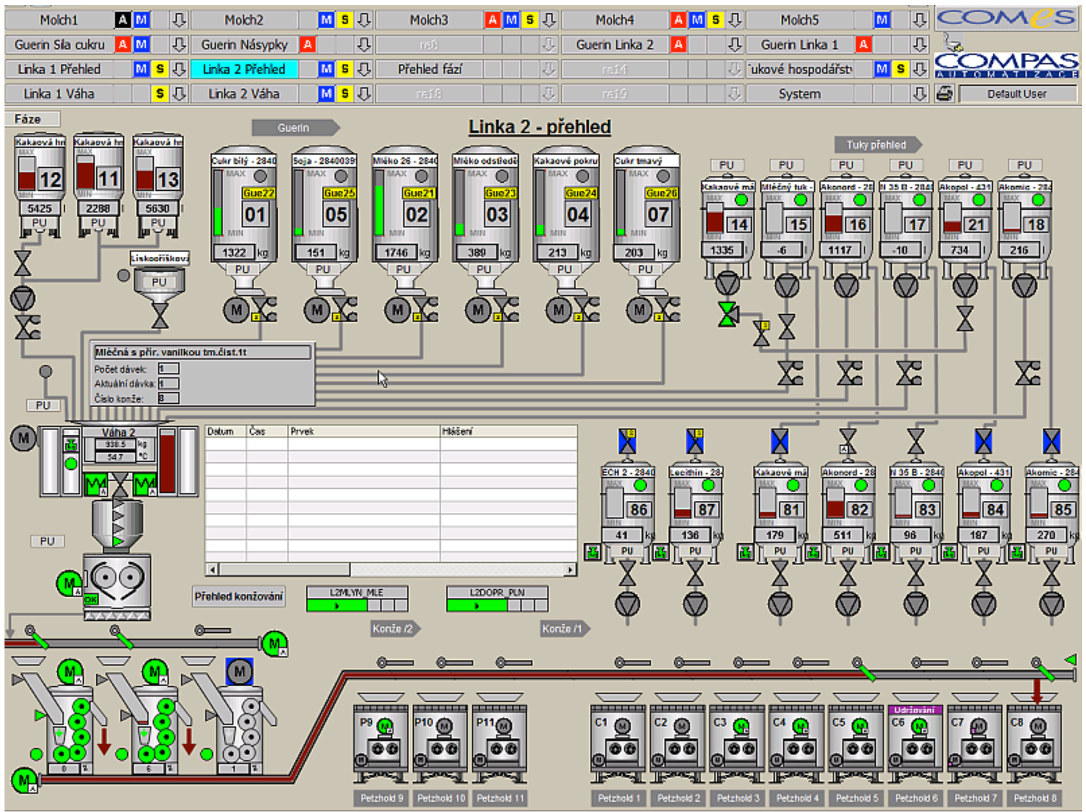
Critiques

The rationale behind using the radial graph is not clear!Why not rectilinear.Maybe to show the cyclic pattern!!!

- ❖ Divided into same size sectors in radial graph.
- ❖ The angle channel is less accurately perceived than rectilinear spatial position channel. [Munzner, Tamara. *Visualization analysis and design*. CRC Press, 2014.pp 166]

Critiques

No evaluation with existing real time monitoring platform



https://www.compas.cz

Conclusion

- Application of Marey's graph in this domain was very effective.
- Two anomaly detection processes were suggested for outlier detection.
- System was tested with real data and they ran case studies for both historical data and real-time data.
- User interviews shows promising results but no evaluation.

Future directions

1. Deployment in real production line
2. Improve scalability
3. The occurrence of outliers in composite events

My suggestion:

- Extend the visualization to group or uncountable products
- Add indicators for sensors and their values in real time system and controllability for stations