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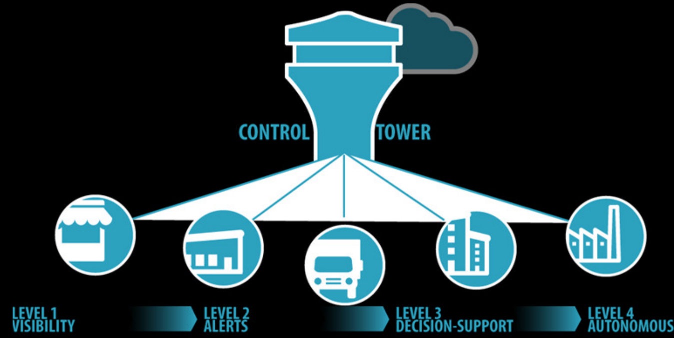

SERVICE CONTROL TOWERS FOR PREDICTIVE MAINTENANCE AND SPARE PARTS PLANNING

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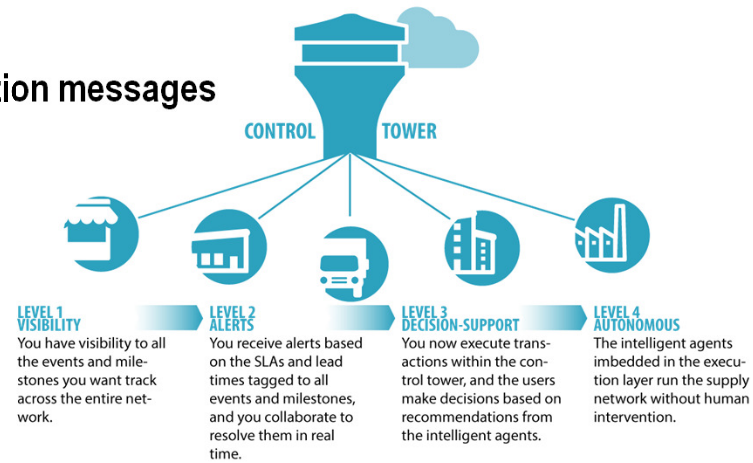
WHAT IS A SERVICE CONTROL TOWER?

TOPAN ET AL. (2020), THE REVIEW PAPER

- **Service control tower (SCT)** is a **centralized hub**
  - uses **real-time data**
  - **integrates processes** and tools across the end-to-end service in the **supply chain**

- Companies use SCTs to **monitor** their supply chain and **generate exception messages**
  - **when projected stock levels deviate** from the tactical plans
  - typically generated based on **business rules**

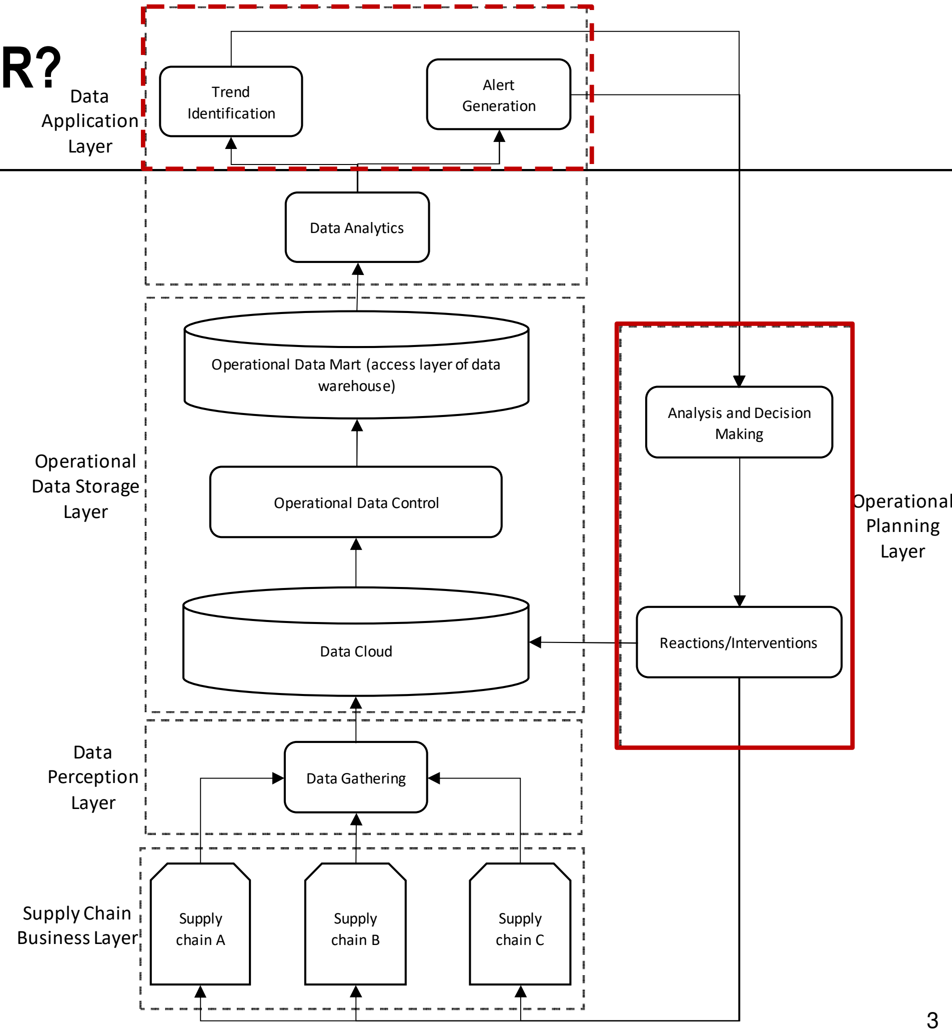
- Planners **review exceptions** and select their **operational interventions**
  - e.g., place an **emergency shipment** or an extra **new buy**.



WHAT IS A SERVICE CONTROL TOWER?

TOPAN ET AL. (2020)

- A typical SCT consists of **five layers** (Shou-Wen, Ying, & Yang-Hua, 2013).
- **Operational planning layer** and **data application layers** are of our interest.
- **Data gathering, storage, supply structure** are related to the ICT or SC infrastructure and **related to strategical or tactical level**

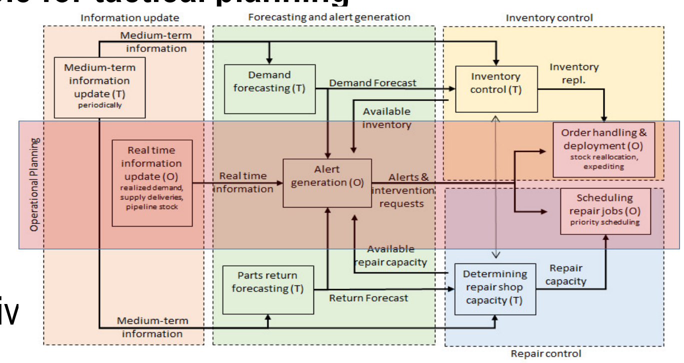


WHAT IS OPERATIONAL PLANNING IN SPARE PARTS PLANNING?

TOPAN ET AL. (2020)

- Decisions about interventions that have **immediate** effect and **influence short-term performance**
  - **Short term**: hours, days, or at most weeks ➔ **So actually short sighted decisions**
  - Interventions whose **lead time shorter than regular replenishments**;

- Decisions are based on **real-time SC information**, which is **not available for tactical planning**
  - inventory **on hand**,
  - **pipeline** stock,
  - number of **parts in repair** or **return**,
  - process **completion time estimates**,
  - **short-term demand info** derived from condition monitoring, preventiv



- **Strategic and tactical decisions**, e.g., supply network, inventory parameters, cannot be influenced in short-term, and therefore, they **are fixed**, but they have an **effect on oper. plan.**

COMPANY SURVEYS

TOPAN ET AL. (2020)

- **Five OEMs** participated in our review, abbreviated *A*, *B*, *C*, *D*, and *E*

- ***A*** : an **IT** company hardware and telecommunication devices
- ***B*** : **semiconductor** industry
- ***C*** *:* **aerospace** industry
- ***D*** : **defense** and security applications
- ***E*** : **material handling** systems

- *The five* have a strong market position/market leader with close ties with their customers

COMPANY SURVEYS

TOPAN ET AL. (2020)

- Mostly SC networks with **2-4 echelons**
- Mostly **slow moving** and **expensive parts**
- Operational planning requires significant effort (**40-90% of the planning team**)

Service structure (current situation)	OEMs				
	A	B	C	D	E
Number of product types	Many (> 1000)	Medium (100-1000)	Many (> 1000)	Few (customized) (< 100)	Medium (customized) (100-1000)
Number of installed bases / Number of customers	Very many (> 10000) / Many (> 1000)	Many (> 1000) / Few (< 100)	Medium (100-1000) / Medium (100-1000)	Few (< 100) / Few (< 100)	Many (> 1000) / Many (> 750)
Number of customers / Type of customers	Many (> 1000) / B2B and B2C	Few (100-1000) / B2B	Few (100-1000) / B2B	Very few (< 100) / B2G	Many (> 1000) / B2B
Number of echelons / Number of warehouses	3-4 echelons / 3 CWs, hundreds of LWs	2-3 echelons / 1 CW, < 50 LWs	2-echelon / 1 CW, < 20 LWs	2 echelon / 1CW, 4 assets as depot	1 echelon / 1CW
Carries out maintenance? / Operates repair shops?	Yes / Yes (as a separate entity)	Yes, onsite / No	No / Yes	No / Yes	Yes, onsite / No
Parts planning: LRU and or SRU/ Number of SKUs	LRU / Many (>10000)	LRU / Medium (1000-10000)	LRU and SRU / Many (> 10000)	LRU and SRU / Medium (1000-10000)	LRU / Medium (1000-10000)
Part characteristics (demand vs price)	All sorts of demand rates and prices	Mostly slow moving (<5 per year) and expensive (> 1000€)	All sorts of demand rates and expensive (> 1000€)	Mostly slow moving (<5 per year) and expensive (> 1000€)	All sorts of demand rates, typically cheap (<100€)
Workforce among operational and tactical planning	Operational: 40% FTEs Tactical: 60% FTEs	Operational: 70% FTEs Tactical: 30% FTEs	Operational: 67% FTEs Tactical: 33% FTEs	Operational: 60-90% FTEs Tactical: 40-10% FTEs	Operational: 90% FTEs Tactical: 10% FTEs

COMPANY SURVEYS – RELATION BETWEEN OPERATIONAL PLANNING AND TACTICAL PLANNING

BASED ON TOPAN ET AL. (2020)

Approaches	**OEMs**				
	A	**B**	**C**	**D**	**E**
No link, Hierarchical, Integrated	Integrated	Integrated	Between no link - hierarchical	No link - Hierarchical – Integrated (depending on service contracts)	NA hence No link

- Only ***A* and *B* use some form of integration** to **update tactical planning when it deviates**.
- **Tactical planning may often be overruled by operational planning** at these OEMs.

COMPANY SURVEYS – INFORMATION CONTENT AND USE
BASED ON TOPAN ET AL. (2020)

Supply and Demand Information Use and Control	OEMs				
	A	B	C	D	E
Getting status update about the external supply (your suppliers') process	3	3	3	2	2
Having control over external supply process	2	2	2	1	1
Having prediction models/demand forecasts	3	3	3	2	3
Using prediction models/forecast in planning operations interventions	3	2	3	1	3

- *The five* all have **information** about their **external supply process**. Yet, they have **limited** or **no control** over their **supply process**.
  - They **often do not use supply** information

- Four of *the five* use **demand forecasts** for operational interventions.

  ➔ **Machine learning is a powerful tool here!**

COMPANY SURVEYS – OTHER MODEL DRIVEN ASPECTS

BASED ON TOPAN ET AL. (2020)

Elements	OEMs				
	A	B	C	D	E
Optimization methods for decision problems	Simple decision rules	Simple decision rules	Simple decision rules	Manual / Simple decision rules (depending on service contracts)	NA
Demand and supply model	Mix of deterministic and stochastic	Mix of deterministic and stochastic	Mix of deterministic and stochastic	Deterministic	NA
Planning horizon	Finite	Finite	Finite	Infinite / Finite (depending on service contracts)	NA

- Operational planning is based on **simple rules (ad-hoc thresholds)** or on **expert knowledge**.
  - **Proactive** or **reactive** interventions

- **Deterministic demand and supply models** are widely used. The uncertainty of demand and supply is often neglected.

- Using a **finite planning horizon**

ALERT GENERATION & PRIORITIZATION

Alert generation and prioritization for a closed loop supply chain of repairable components

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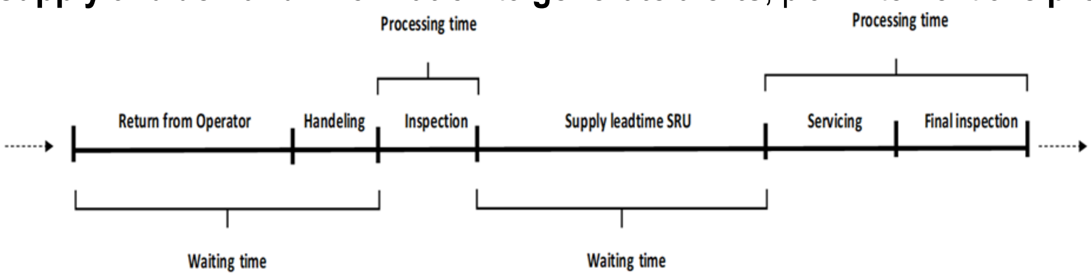
- All *five* use a mostly event-driven **alerts** often **based** on using **thresholds**

- Alert systems generate **too many exception messages**, e.g., on average **300 -2000 alerts** per week.
  - Yet, **a small portion (15% to 50%)** of alerts are identified as **high priority**.
  - **Managing** and **automated processing** of exception messages

- **Using advance supply** and **demand information** to **generate alerts**, plan interventions **proactively**.



- We combine a **data-driven method** (**neural networks**) and a **model-based approach** (**probabilistic model**) to support **human planners** by generating alerts when a supply delay is identified.

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ALERT GENERATION AND PRIORITIZATION FOR A CLOSED LOOP SUPPLY CHAIN OF REPAIRABLE COMPONENTS

ALERT GENERATION & PRIORITIZATION

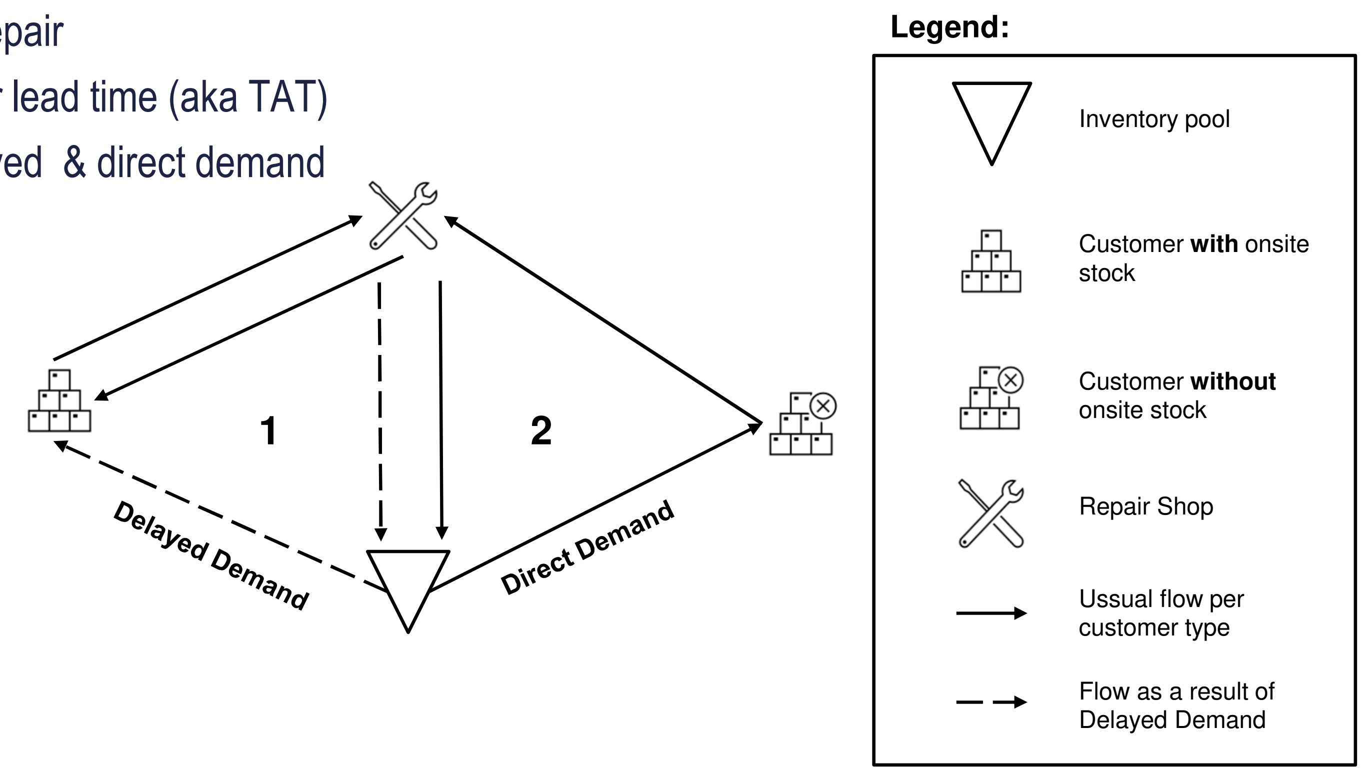
Content

- Supply chain setting
- Methodology
- Repair lead time prediction
- Results
- Fokker Services use case

ALERT GENERATION & PRIORITIZATION

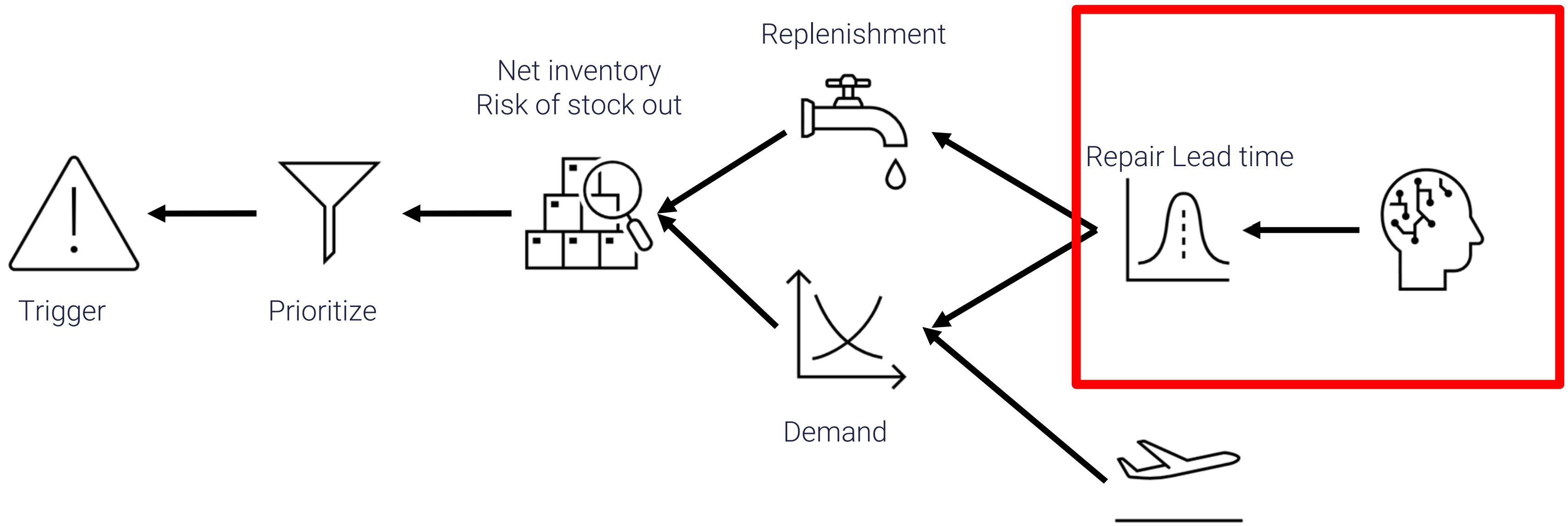
Supply chain setting

- Closed loop supply chain for repairable components
- Replenishment through repair
- Supply lead time = Repair lead time (aka TAT)
- 2 Types of demand: delayed & direct demand



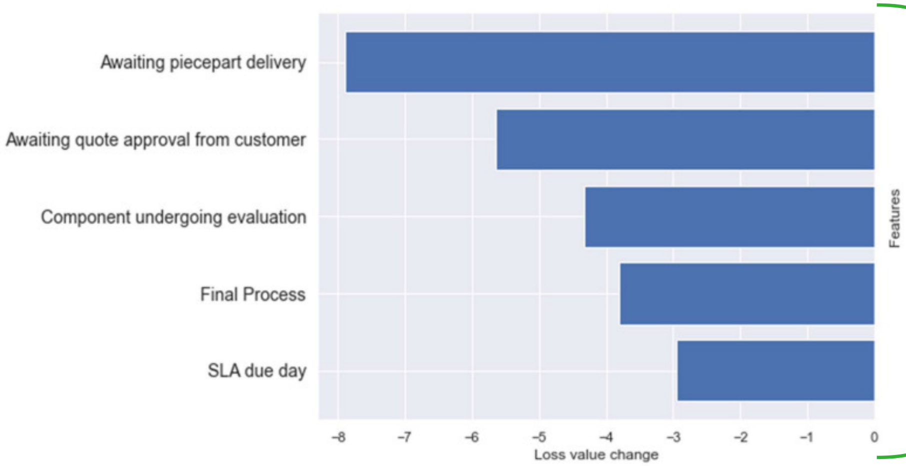
ALERT GENERATION & PRIORITIZATION

Methodology

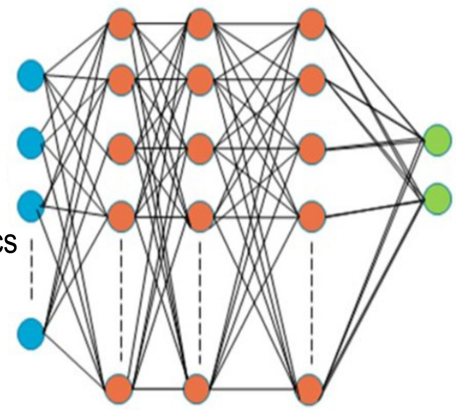


ALERT GENERATION & PRIORITIZATION

Repair lead time prediction



Features:
- Repair progress
- Repair characteristics



Output:
- Parameters of gamma distribution

- Be wary of the effort needed for:
  - Hyperparameter tuning
  - Training, validating and testing
  - Regularization (to overcome overfitting)

ALERT GENERATION & PRIORITIZATION

Prediction results

» Prediction error is of our model is **lower** than the **benchmark**

Model	Negative Log Likelihood	Mean Absolute Error
Featured	2.5	4.15
Featureless	4.5	27.78
Log-Linear Regression	4.8	19.45
Linear Regression	5.25	1.6

» Prediction **accuracy** is **14% higher** than **featureless** approach

Prediction Type	Featured	Featureless
Combined	80.47%	70.70%

» Cost **reduction** of up to **13%** can be gained

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VALUE OF PREDICTION IS IN WHAT YOU DO WITH IT

IMPLEMENTATION FOR FOKKER SERVICES

Implementation for Fokker Services

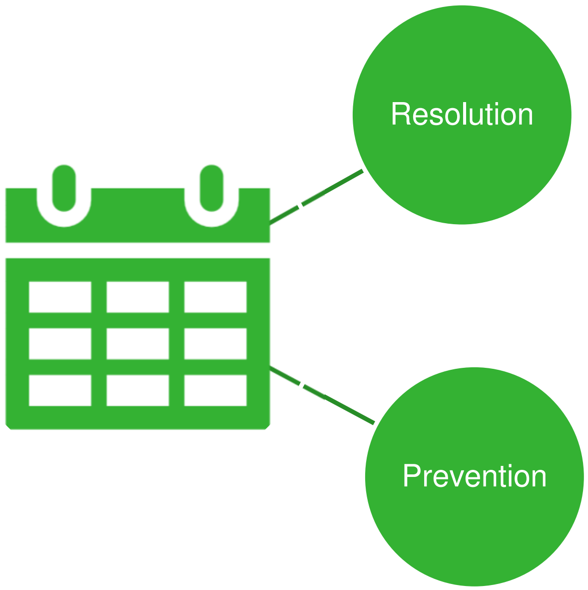
Ingredients to consider

- Implementation aspects to consider:
  - **Business Intelligence (BI):**
    - Understand the **users** and their **objectives (**look at it from end user’s point of view**)**
    - Put **thoughts** and **experiment** with the **user interface** (maybe consider demonstrators)
    - **Differentiate** between **must know** and **nice to know** (prevent information overflow)
  - **Process:**
    - Find **alignment** with current **activities**/**processes (**tools must fit the need**)**
    - **Phased** and/or **parallel** implementation (instead of big bang replacement)
  - **Human**:
    - Early **involvement** and **recurring** feedback **sessions (**build on ownership**)**
    - **Listen** to the end user and **implement improvements** in short iteration (Build on trust**)**

Implementation for Fokker Services

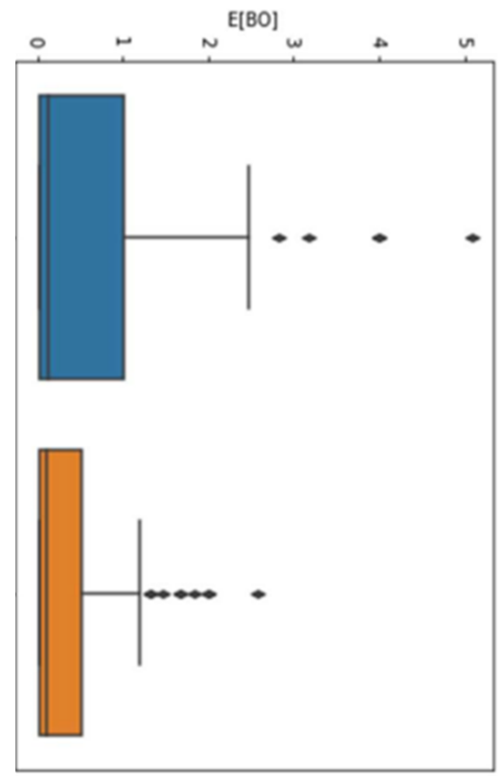
Operationalization

Daily management



- Activities **after** OTD exceedance
- All hands on deck
- **Costly** in terms of **time** & **resources**

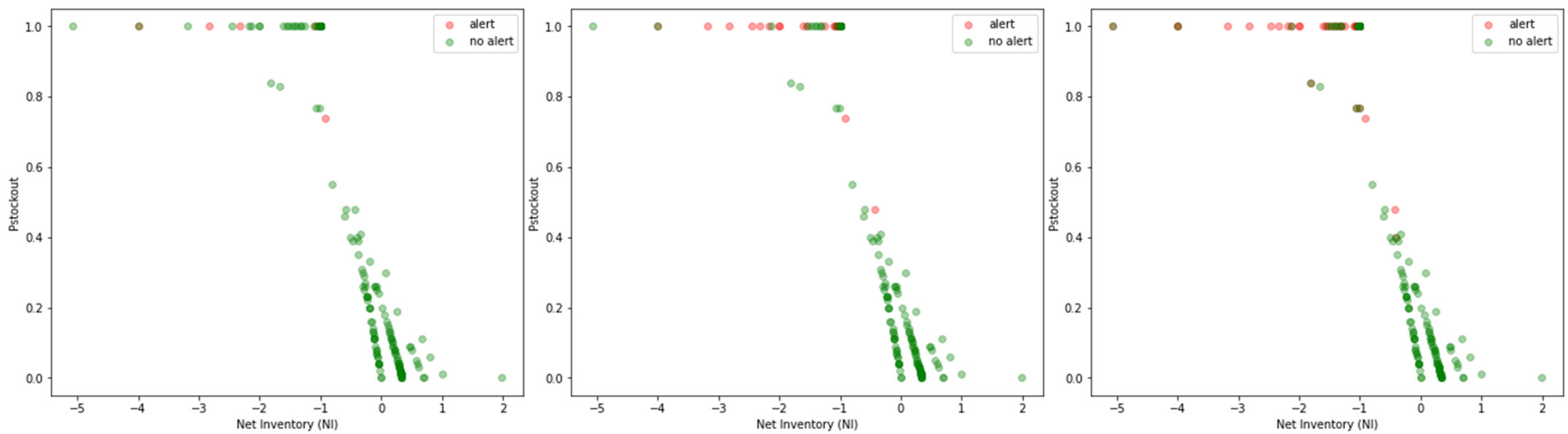
- **Early** warnings
- **Constrained** by **capacity**
- **False** predictions



Implementation for Fokker Services

Illustrative example for inventory control | Dark cockpit principle

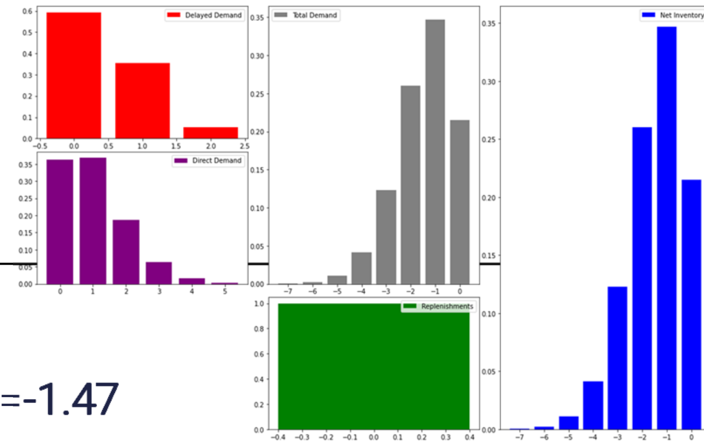
» Prediction for one planning instance with varying capacity constraint

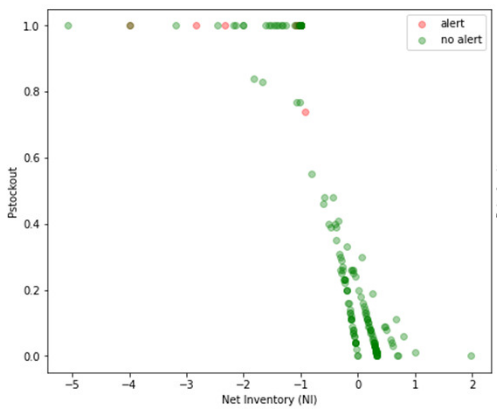


Capacity

Implementation for Fokker Services

Illustrative example for inventory control | Zooming in





- Net inventory at t0 = 0
- Net Inventory at t0 + T=**-1.47**
- Probability of stock out =78.0%
- Expected Demand = 1.47
  - Direct Demand: 1.01
  - Indirect demand: 0.46
- Expected replenishment: 0
  - Replenishment orders in pipeline = 2

- Possible interventions:
  - Reduce Indirect demand occurence through expediting the customer repair (impact on net inventory ~ +0.46)
  - Increase the replenishment probability through expediting (impact on net inventory ~+2)
  - Joint expediting (impact on net inventory ~ +2.46)

Thank you for listening!

Questions?

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