SafeDrones: Real-Time Reliability Evaluation of UAVs using Executable Digital Dependable Identities

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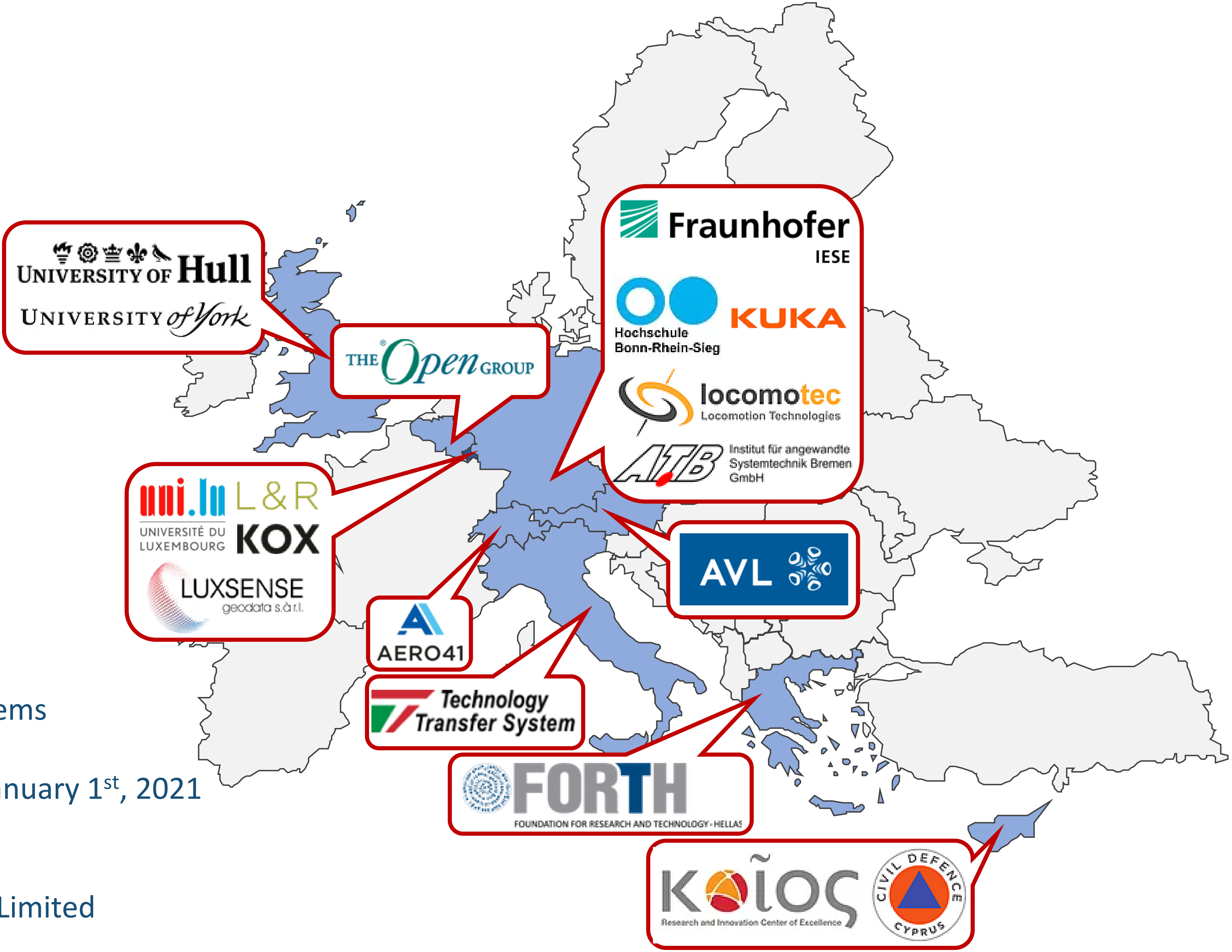
SESAME

SECURE AND SAFE MULTI-ROBOT SYSTEMS



- **Se**cure and **Sa**fe **M**ulti-Robot Systems
- Funding: H2020-ICT-2020-2
- Duration: 3 Years, Starting from January 1st, 2021
- 17 Partners
- ~ 7M € Budget
- Coordination by The Open Group Limited

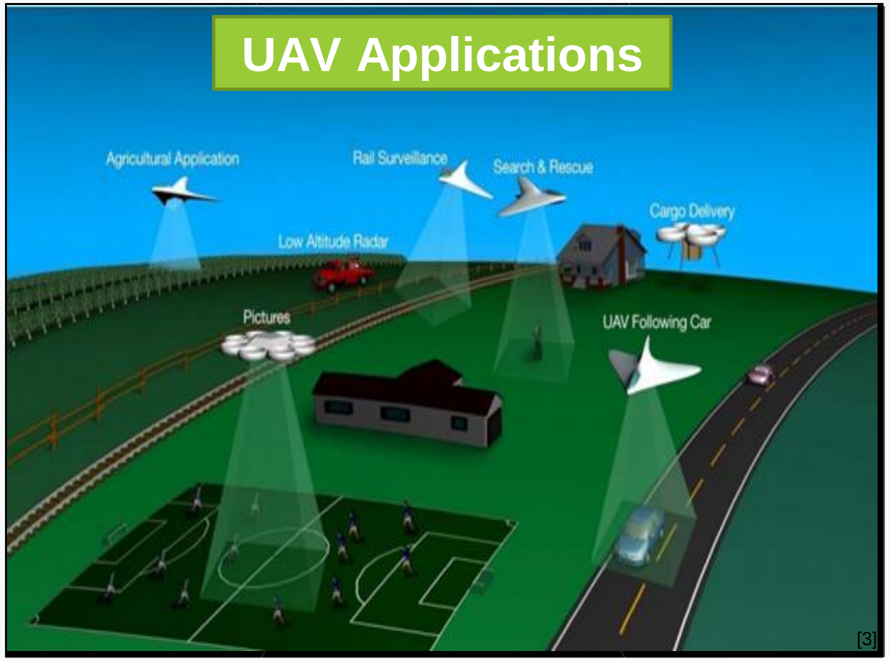
Table of Content

What we are going to discuss

Applications of Drones

Agricultural

Search and Rescue

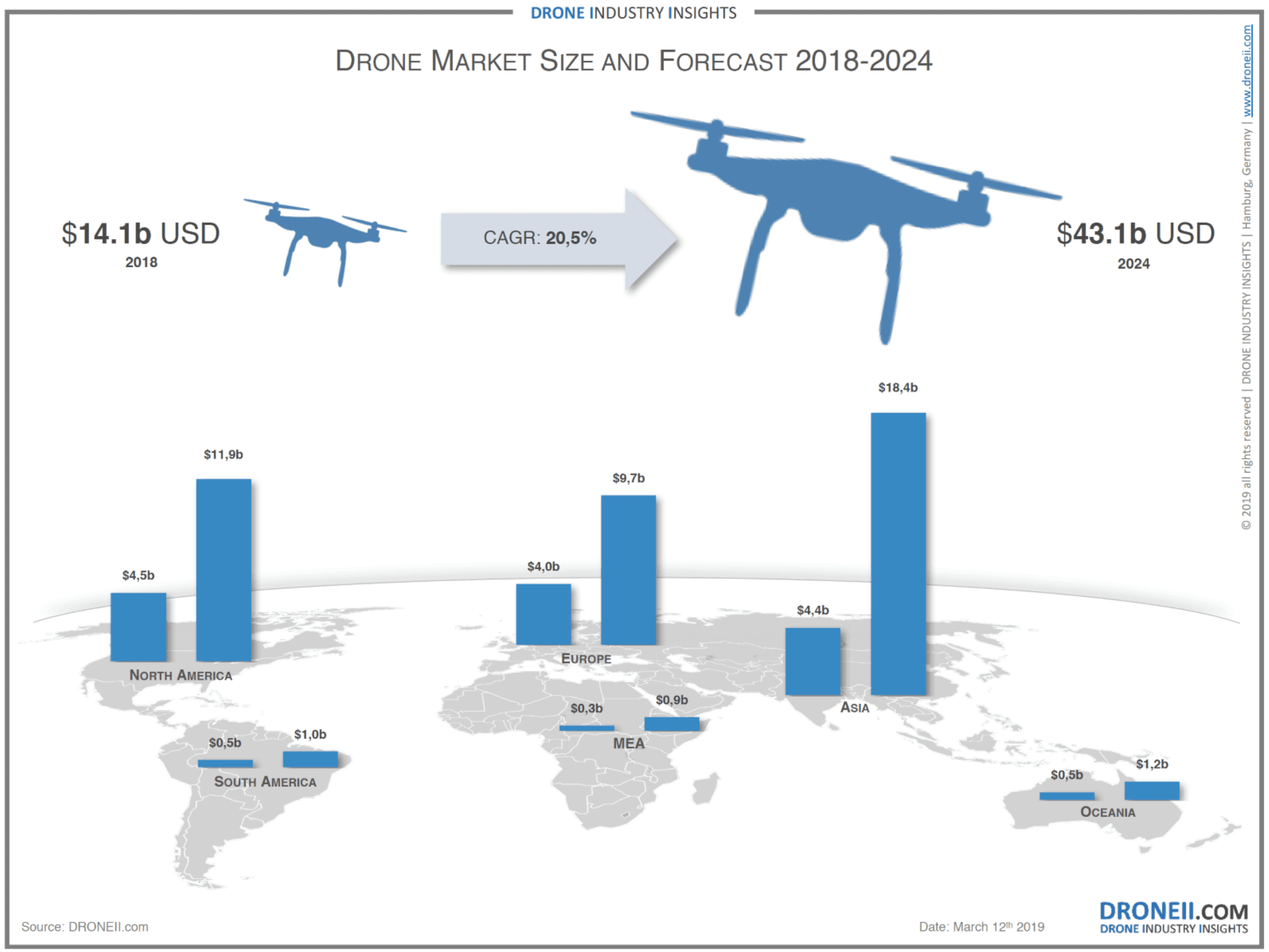


Cargo Delivery

Entertainment

Drones Market

A quick report



Reference: www.droneii.com

UAV-like eVTOLs

Airbus Air Taxi

EHANG 216

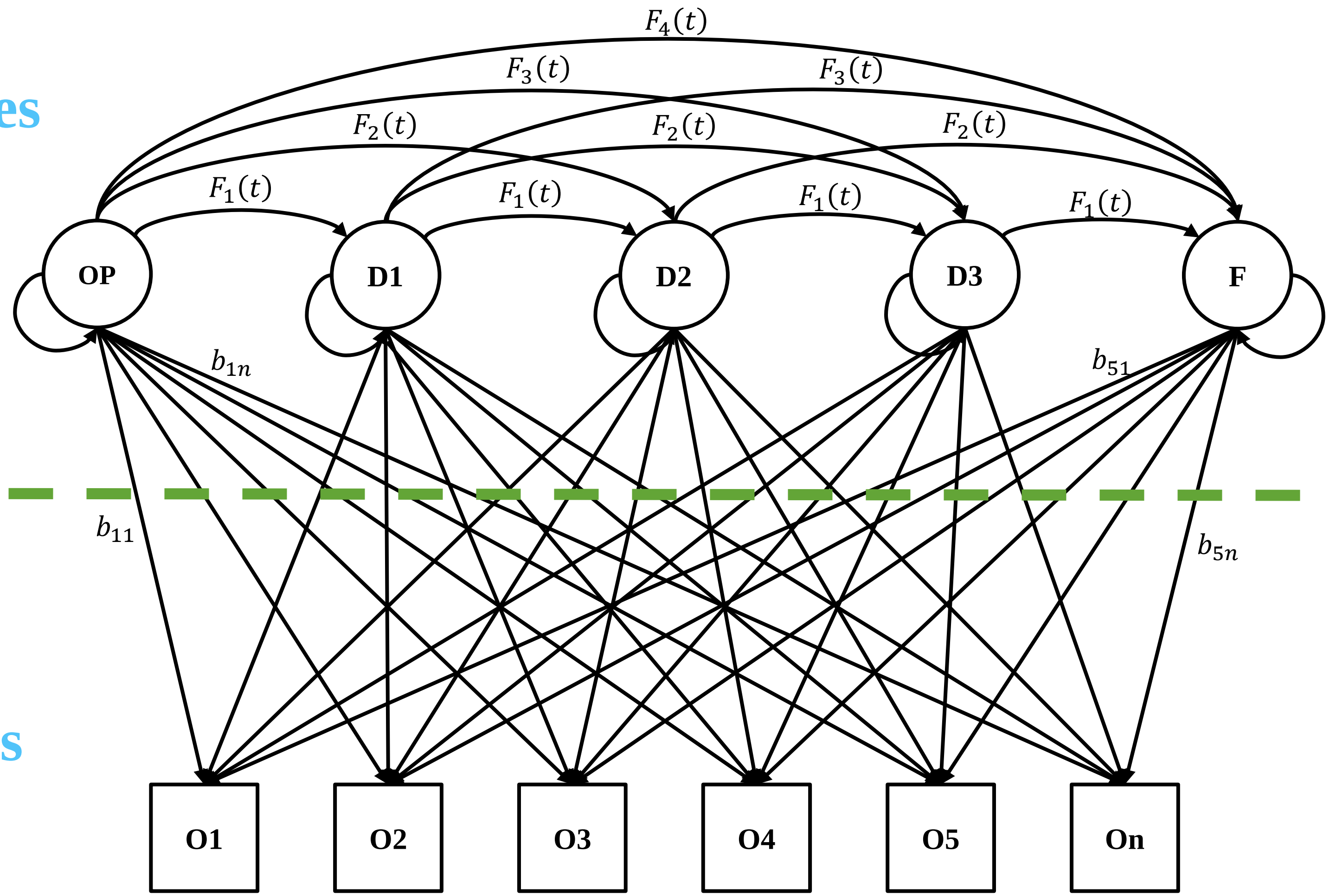
Reference: www.evtol.com

Background

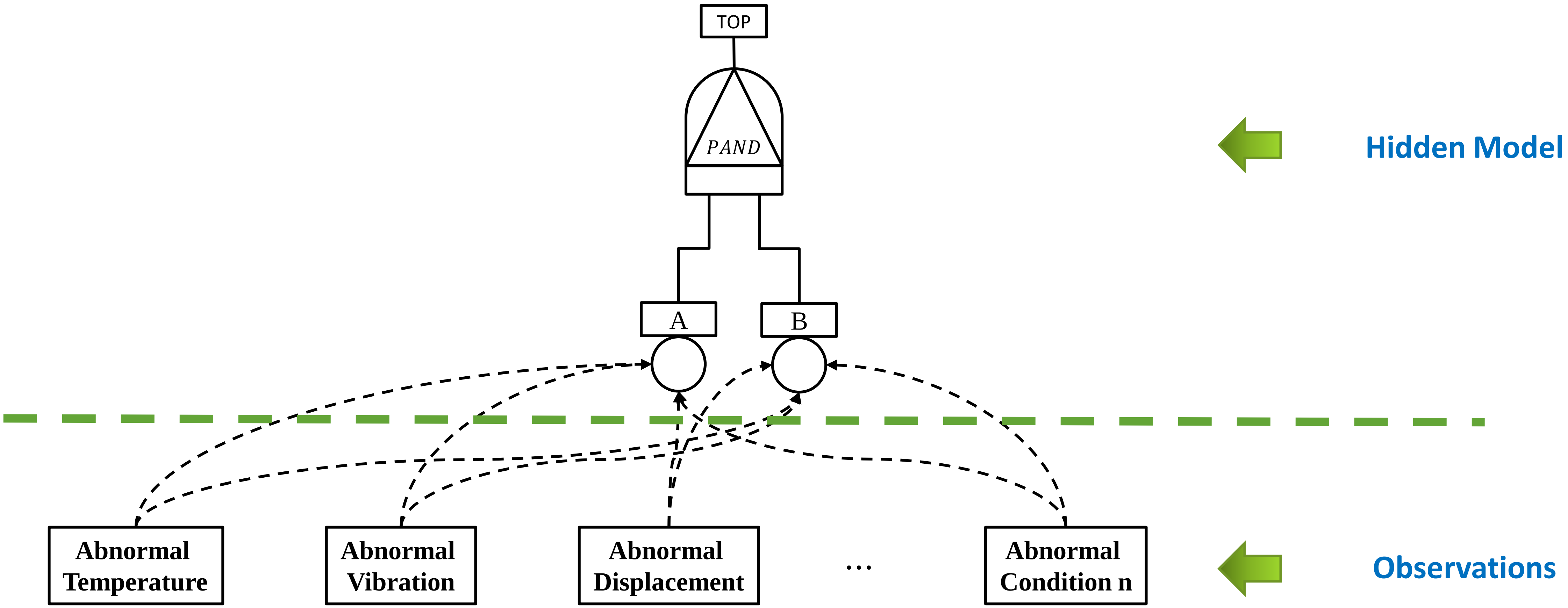
A Simple Structure of Hidden Markov Model

Hidden States of System's Operation

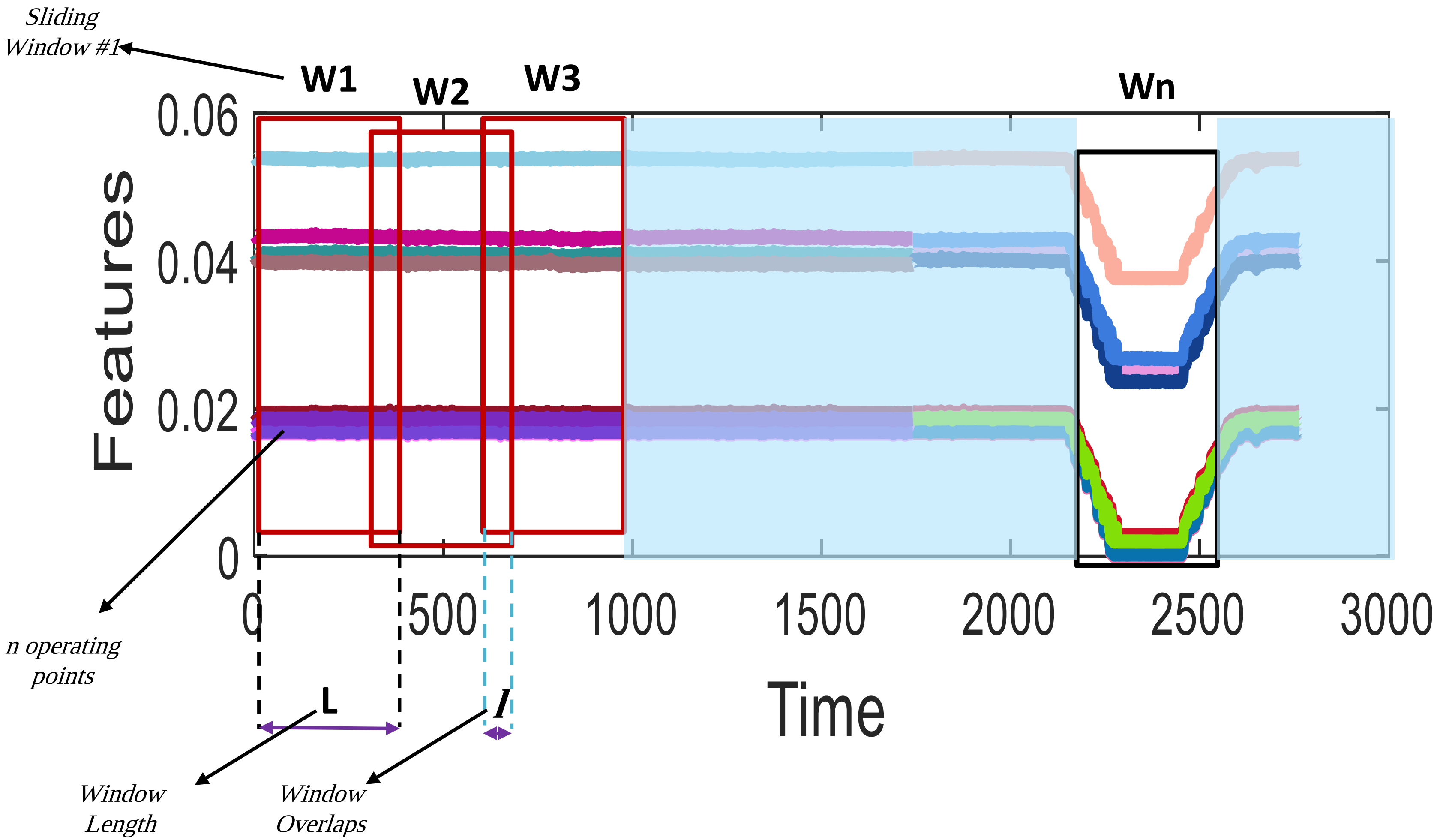
System's Observations



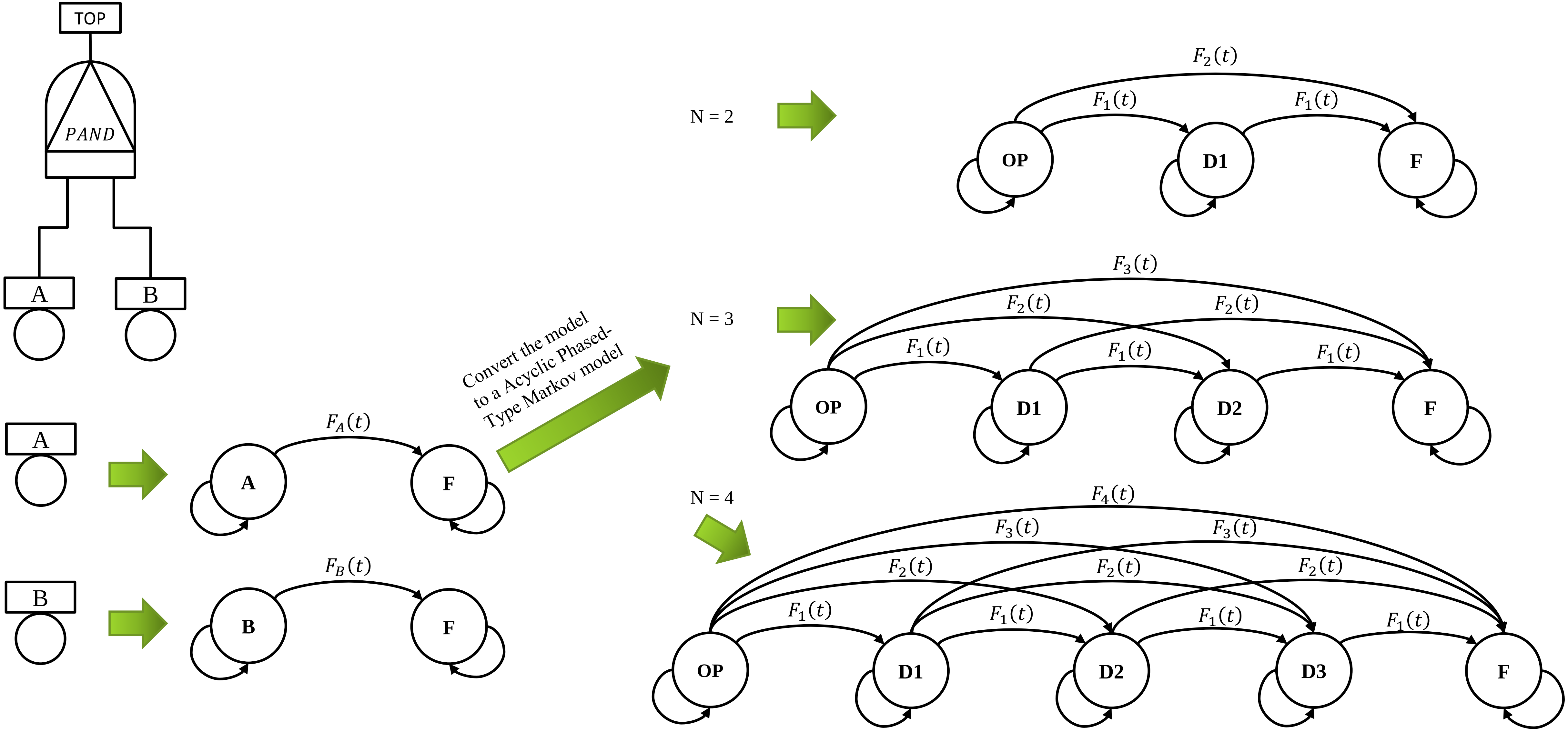
Merging the Idea of Hidden Markov Model with DFT



Sliding Window-based Diagnostic and Prognostic

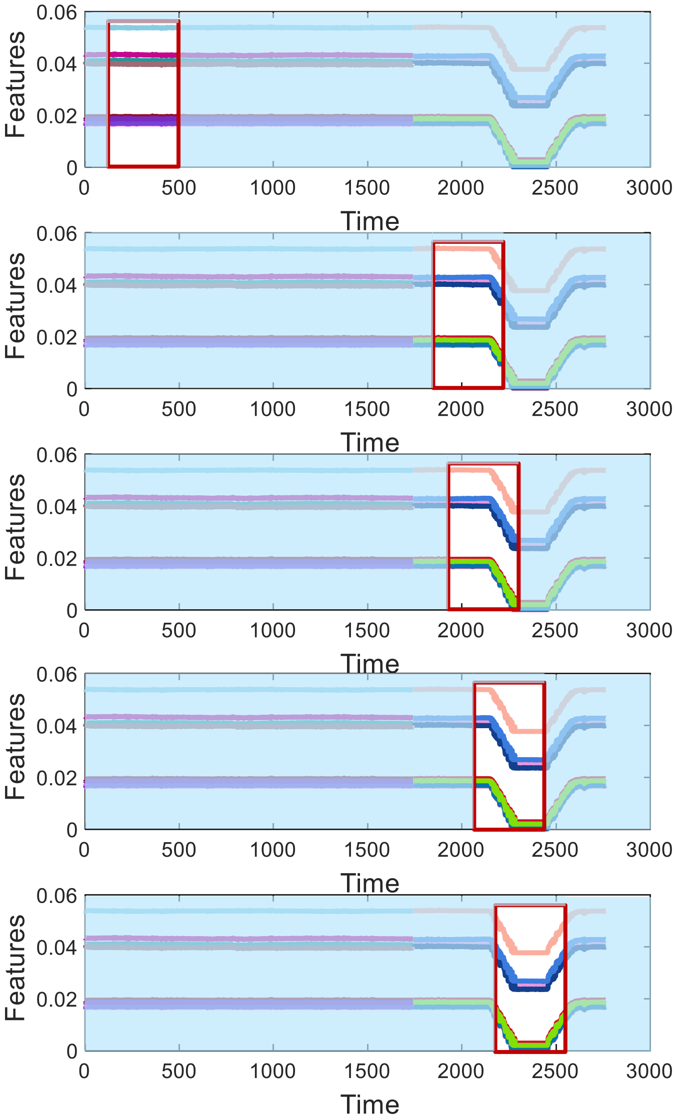


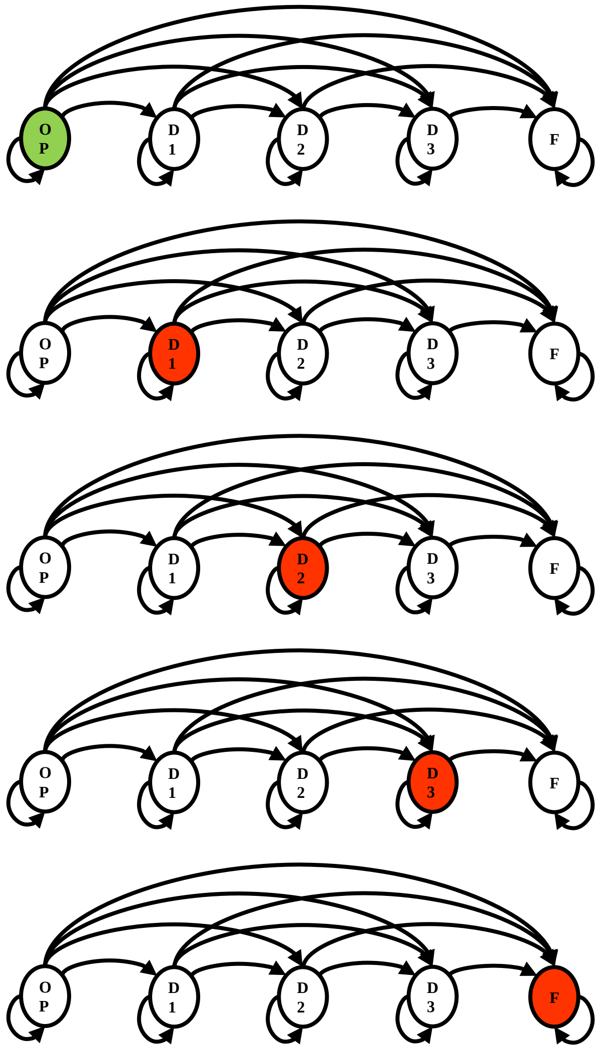
A Basic Event in DFT and Phased Type Markov Model

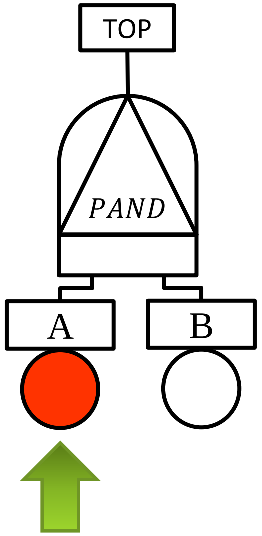


Trivedi, K., & Bobbio, A. (2017). Phase-Type Expansion. In *Reliability and Availability Engineering: Modelling, Analysis, and Applications* (pp. 551-574). Cambridge: Cambridge University Press. doi:10.1017/9781316163047.020

Sliding Window-based Diagnostic and Prognostic







Calculating the Probability to Failure and also Mean Time To Failure (MTTF)

SafeDrones

SafeDrones Project Goal

Reliability and Safety Modelling

Providing safety and reliability models for different parts of Drones.

Safety and Reliability Monitoring

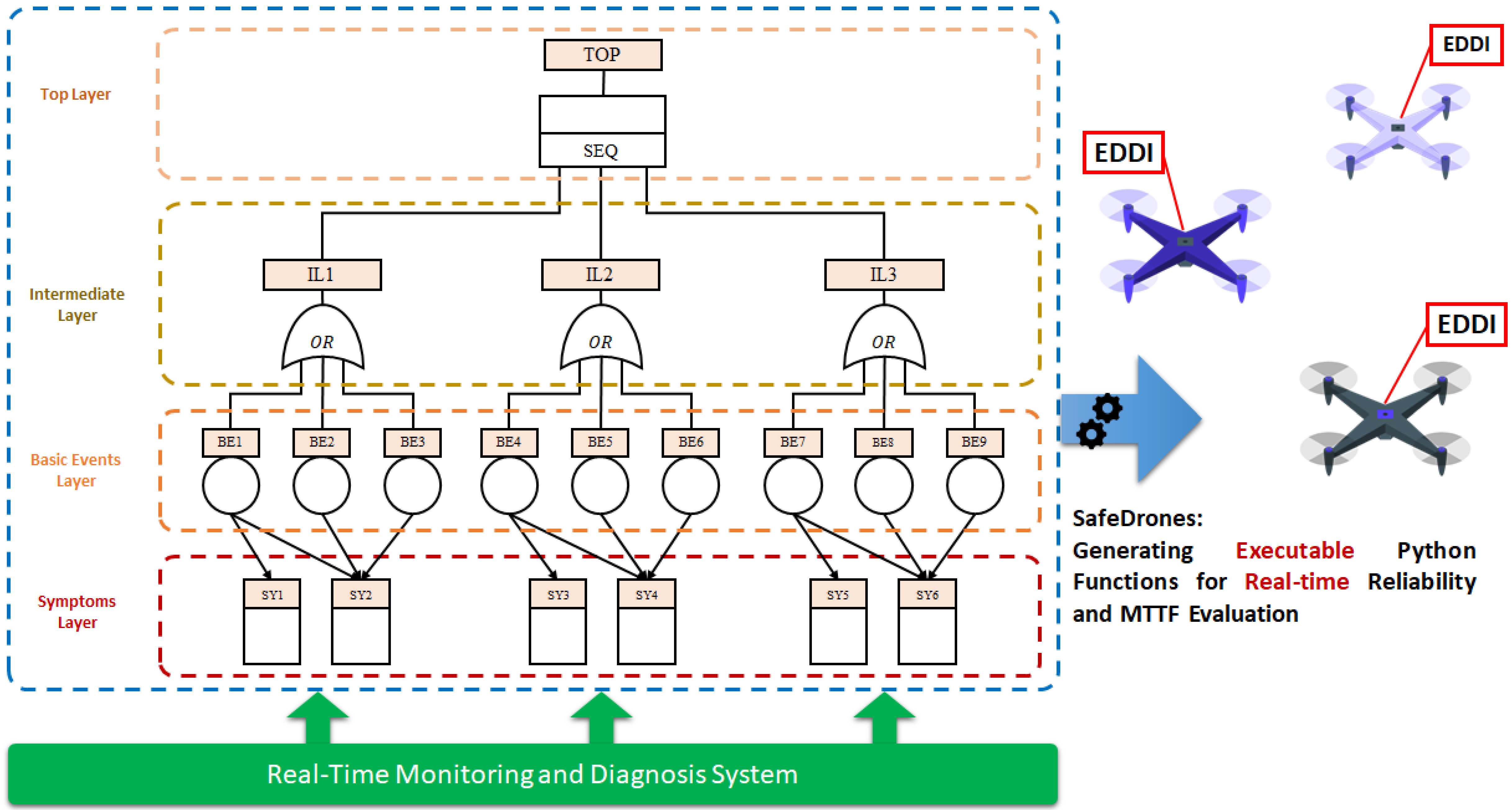
Online safety and reliability monitoring of Drones.

EDDI: Executable Digital Dependable Identifier

Providing EDDI functions to be executed on robot embedded system.

SafeDrones

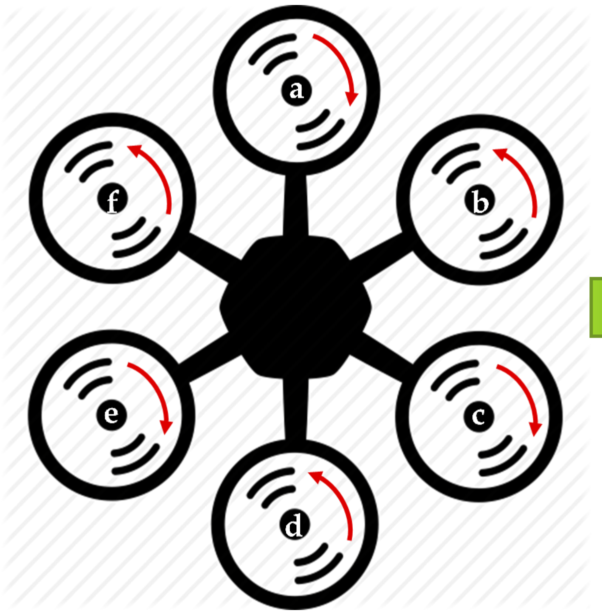
GitHub **https://github.com/koo-ec/SafeDrones**

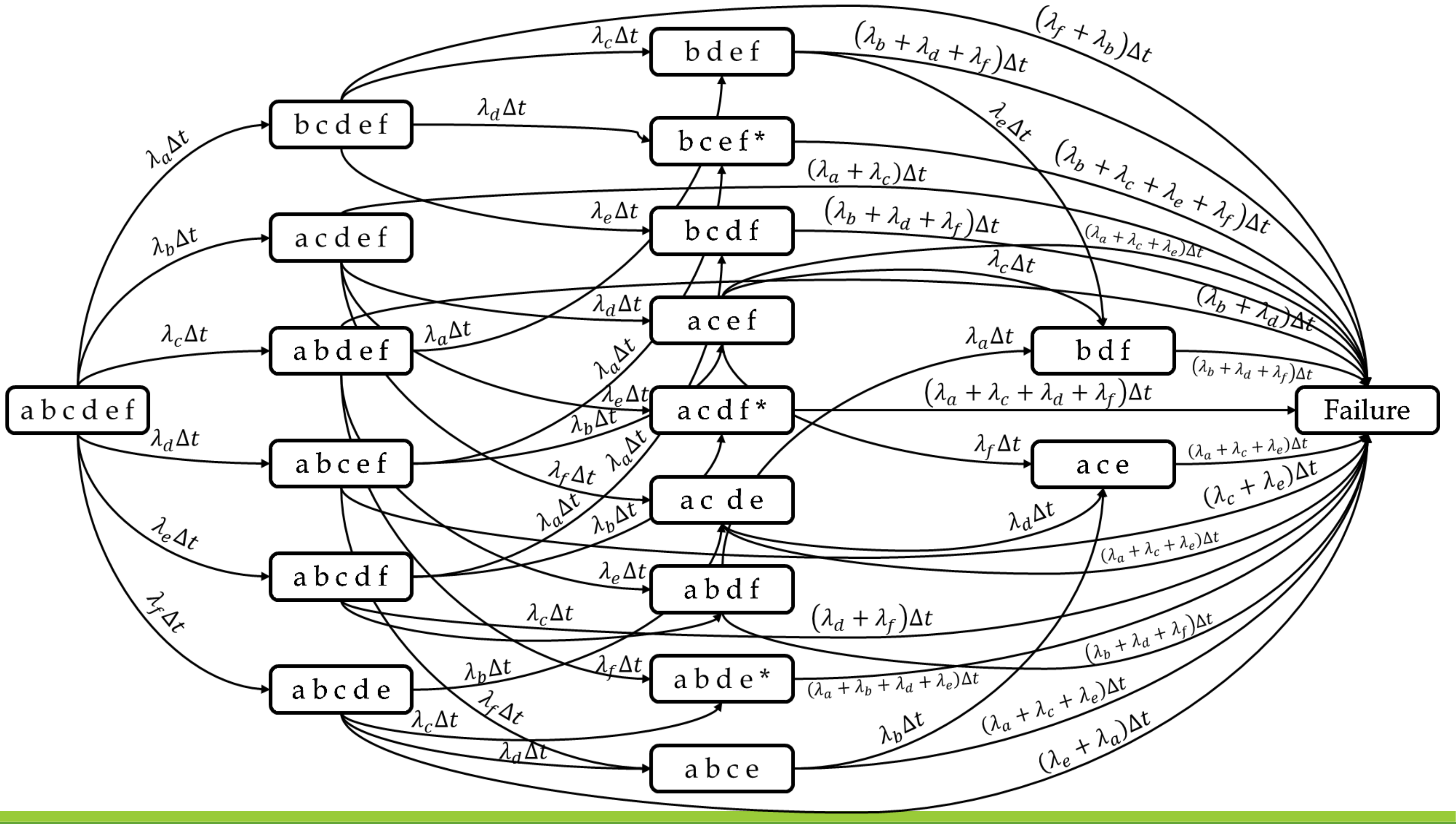

Top Layer
TOP
SEQ
Intermediate Layer
IL1
IL2
IL3
OR
OR
OR
Basic Events Layer
BE1
BE2
BE3
BE4
BE5
BE6
BE7
BE8
BE9
Symptoms Layer
SY1
SY2
SY3
SY4
SY5
SY6
Real-Time Monitoring and Diagnosis System
EDDI
EDDI
EDDI
SafeDrones:
Generating Executable Python Functions for Real-time Reliability and MTTF Evaluation

Propulsion System

Markov Modelling

Hexa-Copter PNPNPN Configuration

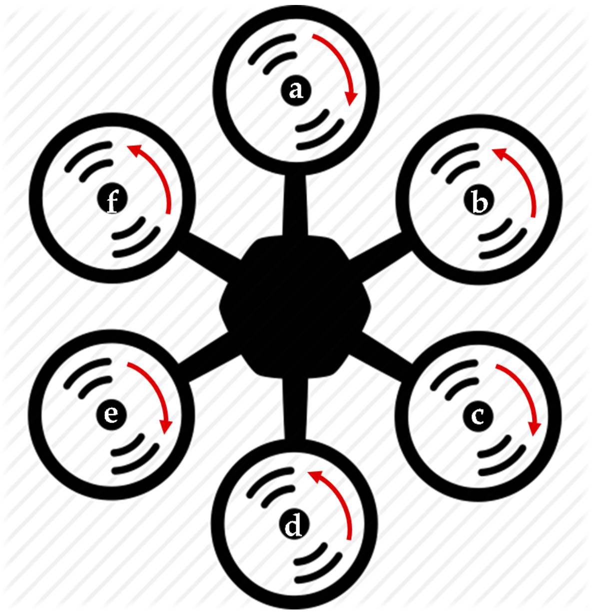


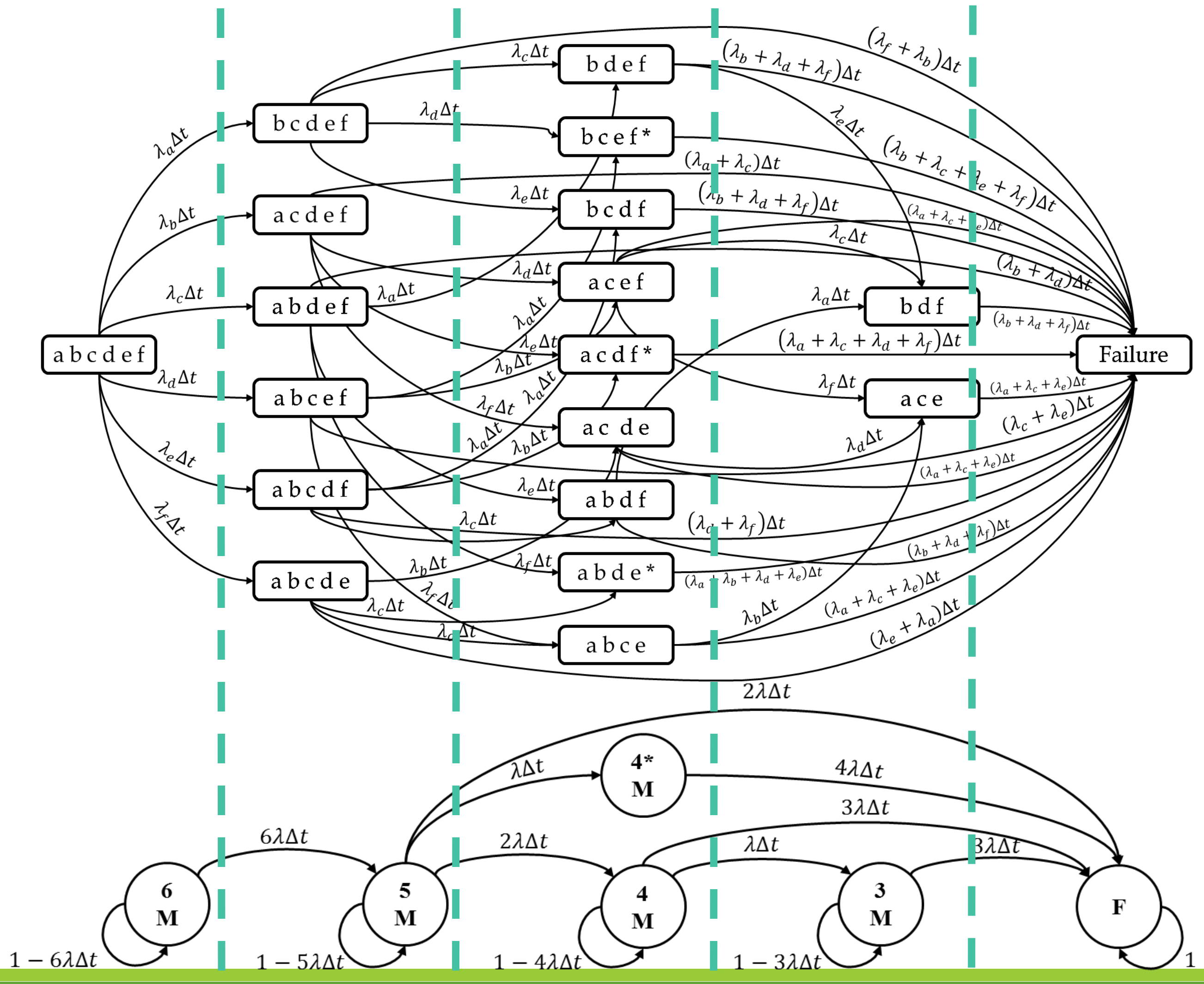


Aslansefat, K., Marques, F., Mendonça, R., & Barata, J. (2019, May). A Markov process-based approach for reliability evaluation of the propulsion system in multi-rotor drones. In *Doctoral Conference on Computing, Electrical and Industrial Systems* (pp. 91-98). Springer.

Simplified Markov Model

Hexa-Copter PNPNPN Configuration





$$\lambda = \lambda_a = \lambda_b = \lambda_c = \lambda_d = \lambda_e = \lambda_f$$

Aslansefat, K., Marques, F., Mendonça, R., & Barata, J. (2019, May). A Markov process-based approach for reliability evaluation of the propulsion system in multi-rotor drones. In *Doctoral Conference on Computing, Electrical and Industrial Systems* (pp. 91-98). Springer.

Markov Modelling

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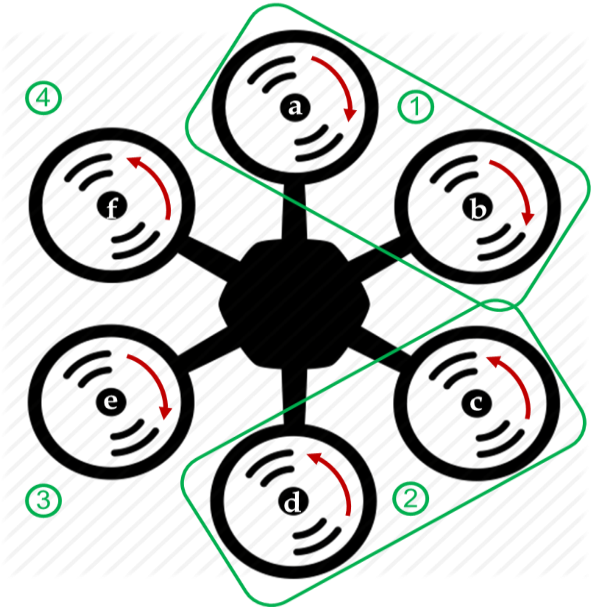

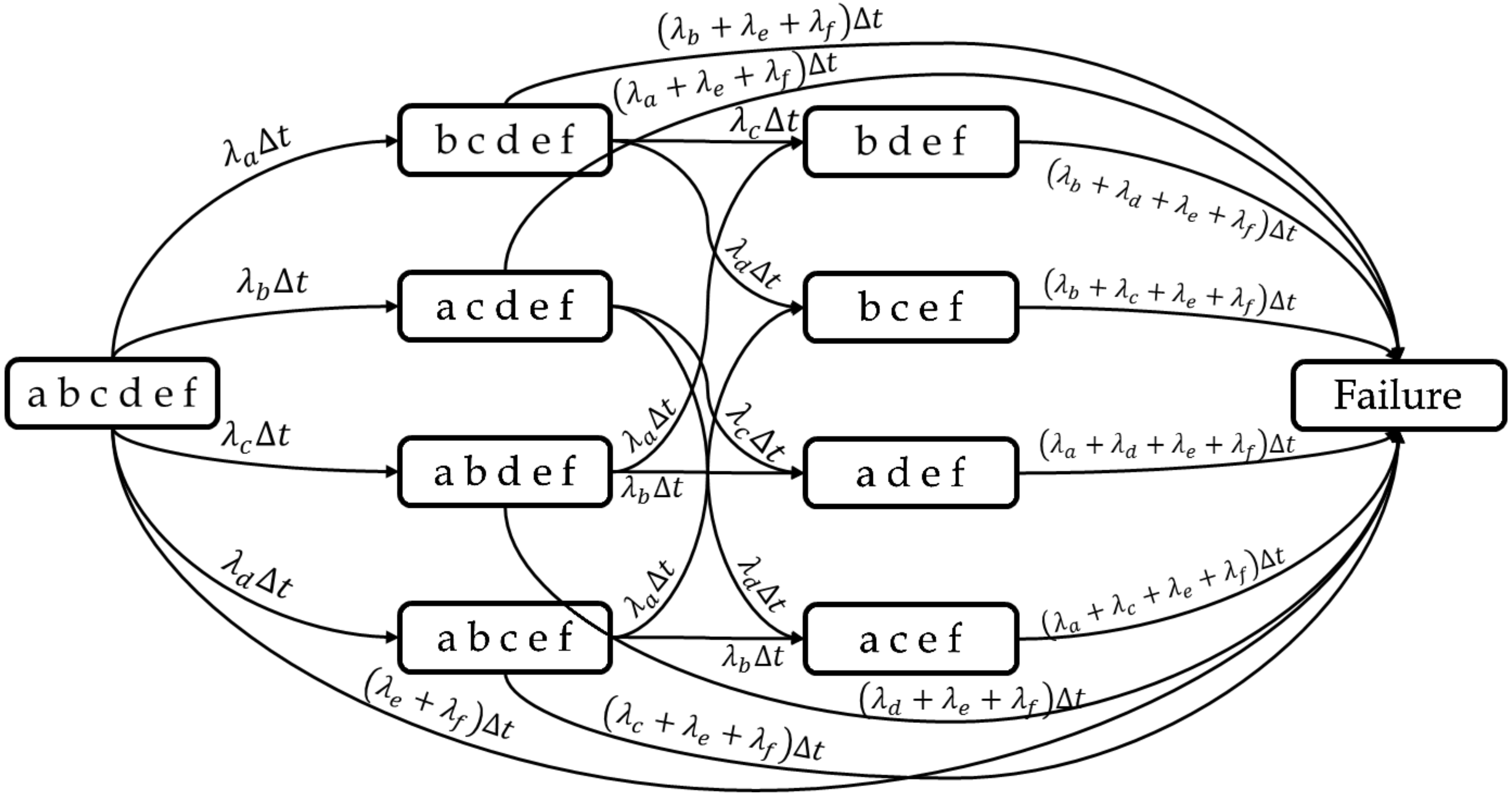

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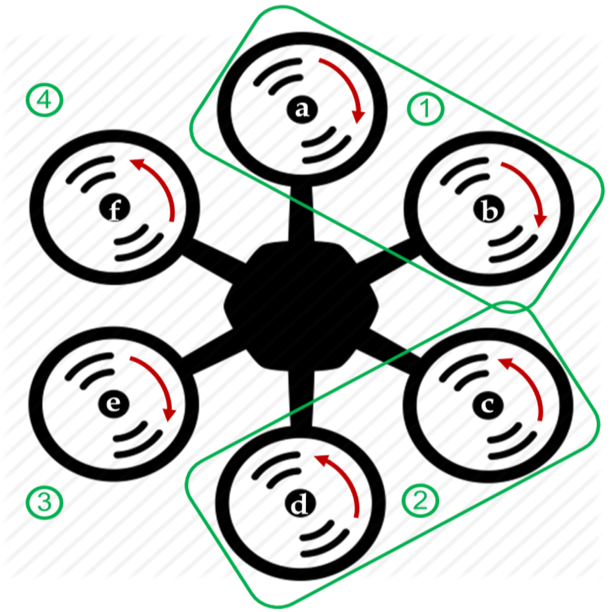

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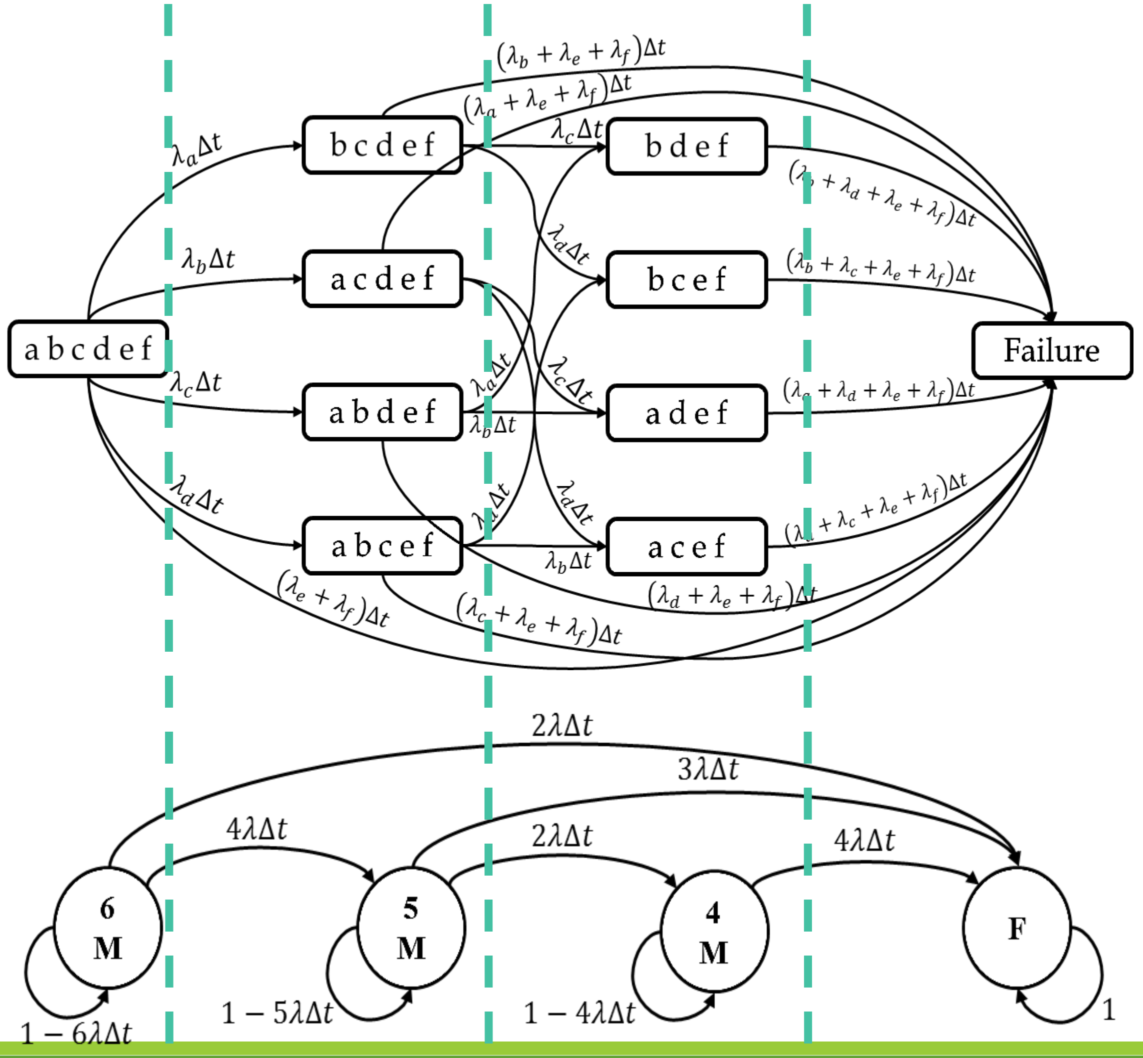
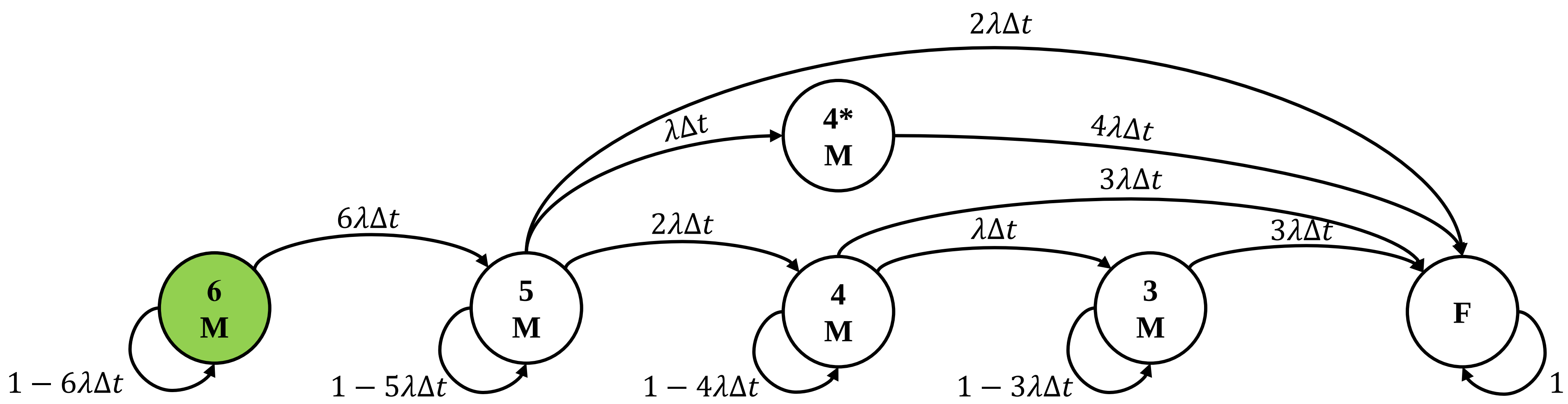
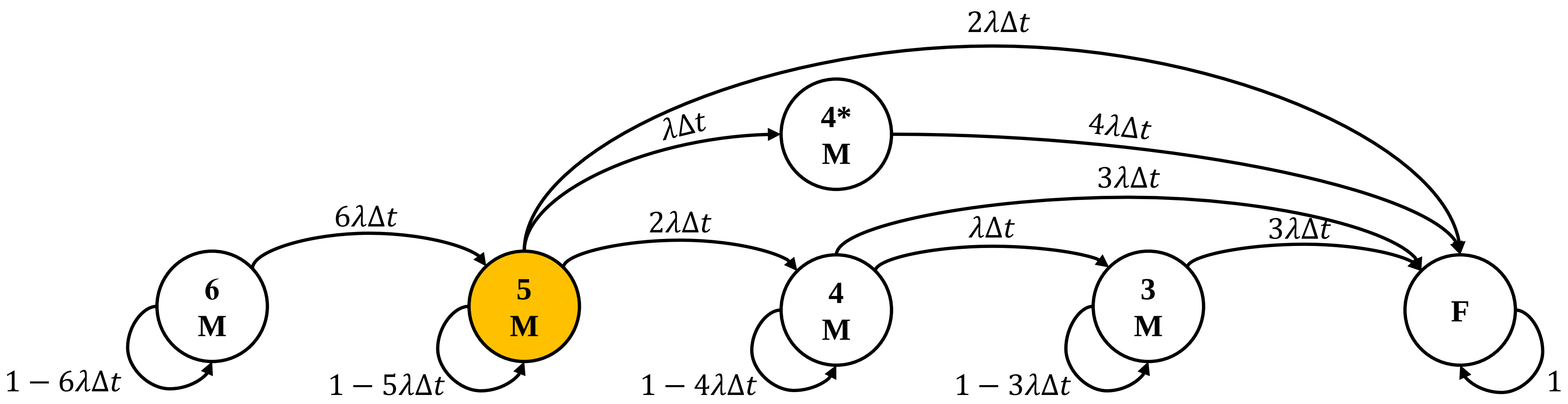


Aslansefat, K., Marques, F., Mendonça, R., & Barata, J. (2019, May). A Markov process-based approach for reliability evaluation of the propulsion system in multi-rotor drones. In *Doctoral Conference on Computing, Electrical and Industrial Systems* (pp. 91-98). Springer.



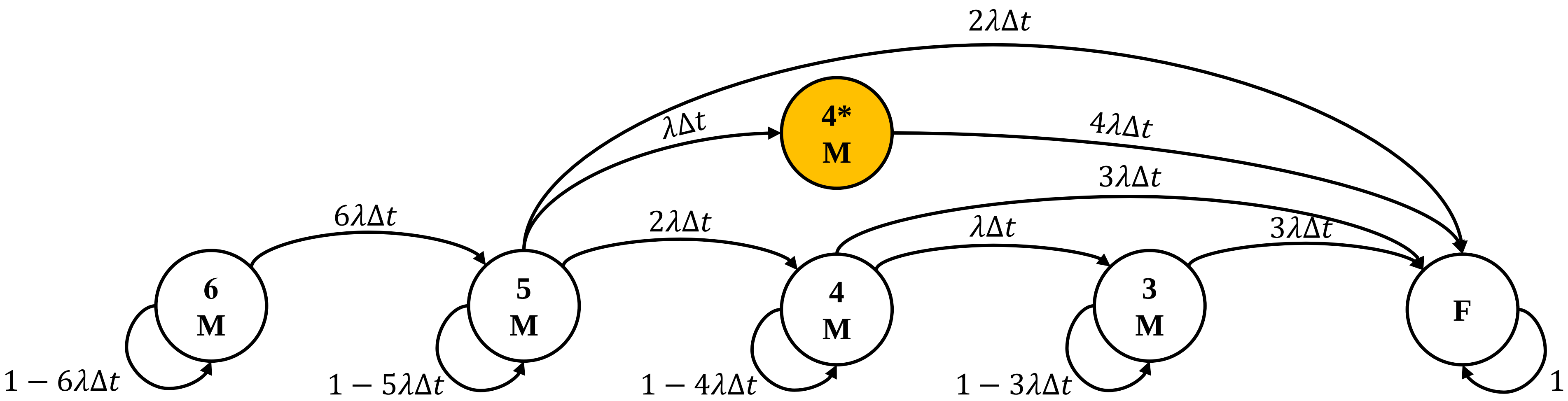

```
P_Fail, MTTF = Motor_Failure_Risk_Calc([1,1,1,1,1,1], 'PNPNPN', 0.001, 100)

print(P_Fail)

print(MTTF)
```

```
0.0489641066173940
483.333333333333
```



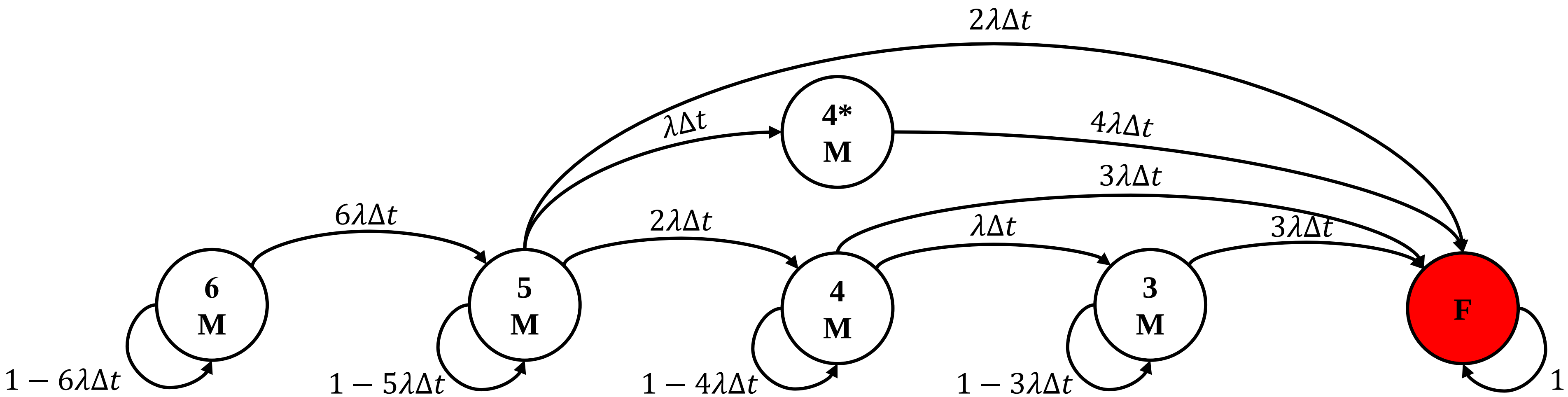

```
P_Fail, MTTF = Motor_Failure_Risk_Calc([0,1,1,1,1,1], 'PNPNPN', 0.001, 100)

print(P_Fail)

print(MTTF)
```

```
0.195392392995276
450.000000000000
```



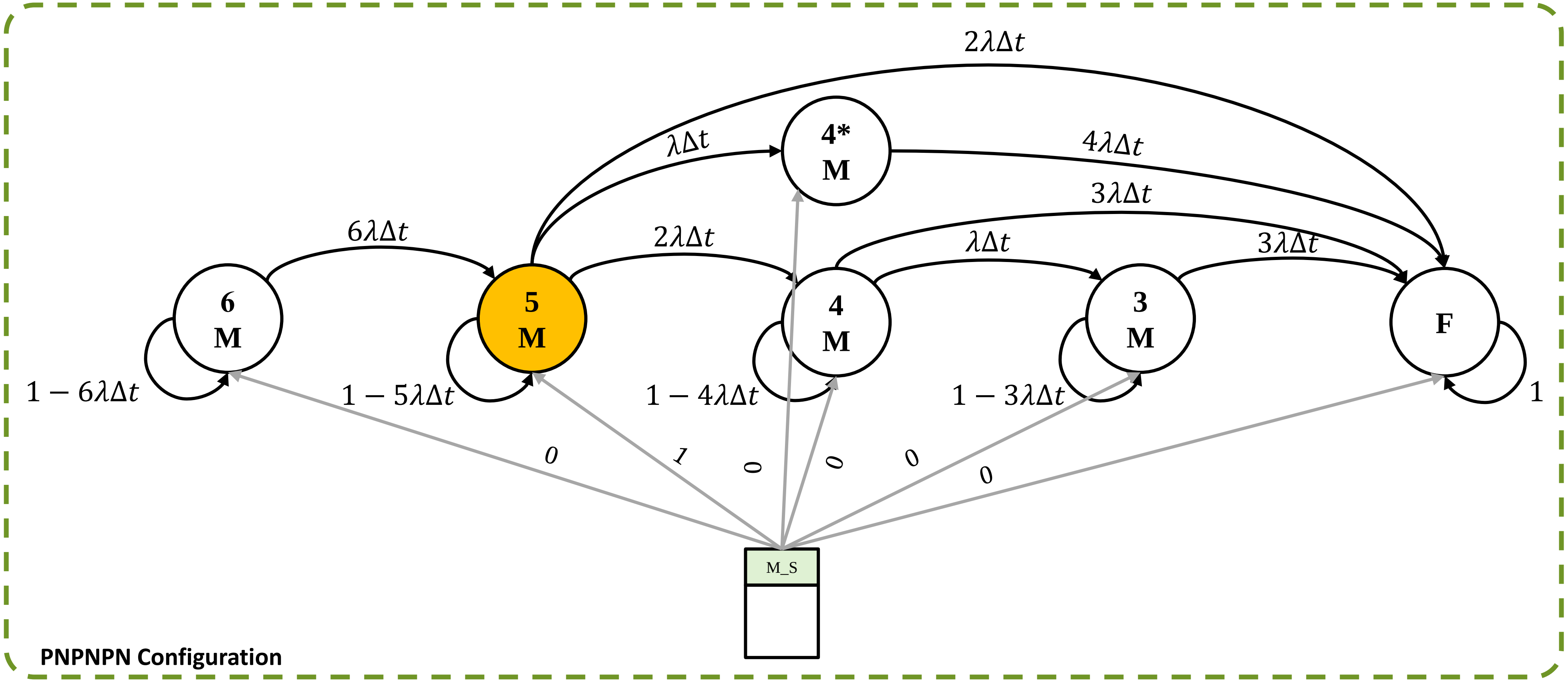

```
P_Fail, MTTF = Motor_Failure_Risk_Calc([0,1,1,0,1,1], 'PNPNPN', 0.001, 100)

print(P_Fail)

print(MTTF)
```

```
0.329679953964361
350.000000000000
```



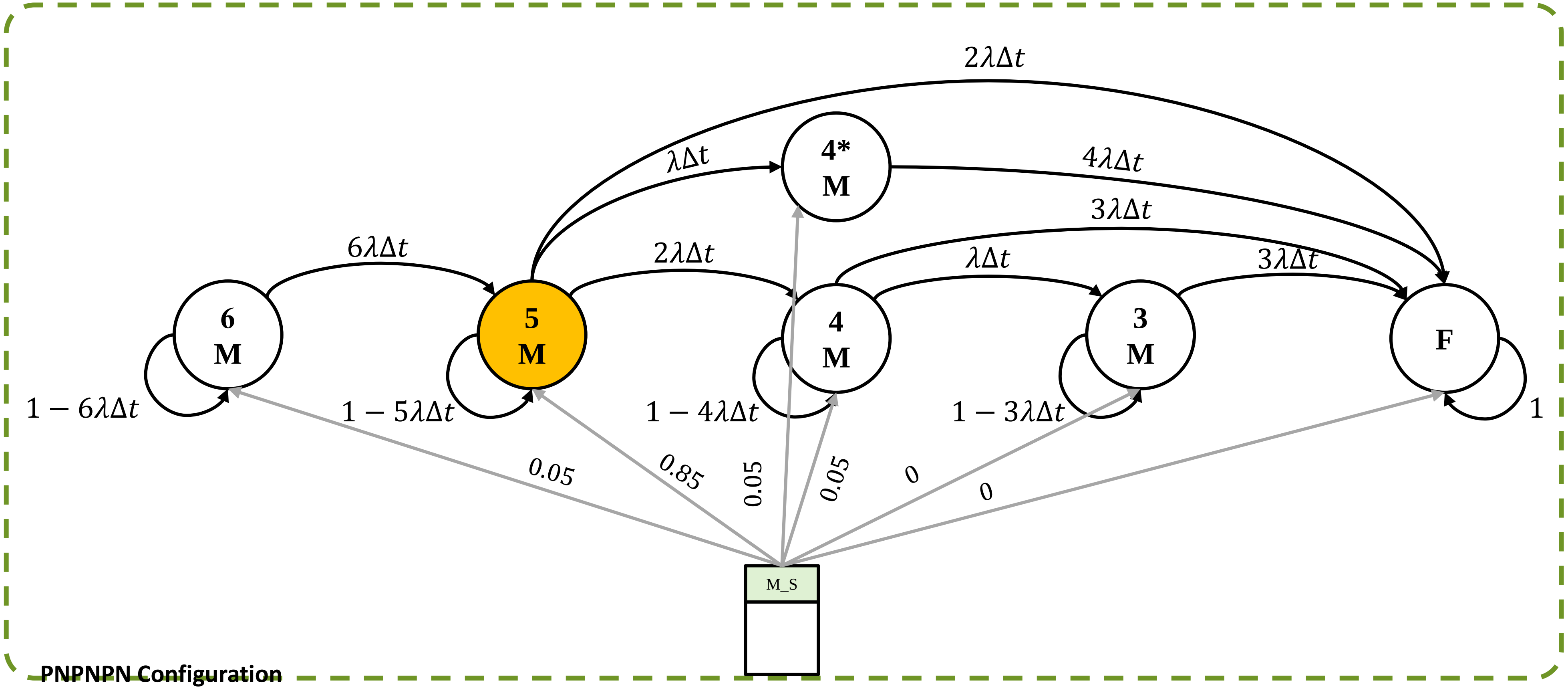

```
P_Fail, MTTF = Motor_Failure_Risk_Calc([0,1,1,0,1,1], 'PNPNPN', 0.001, 100)

print(P_Fail)

print(MTTF)
```

```
0.329679953964361
350.000000000000
```




```
P_Fail, MTTF = Motor_Failure_Risk_Calc([0,1,1,1,1,1], 'PNPNPN', 0.001, 100)

print(P_Fail)

print(MTTF)
```

```
0.195392392995276
450.000000000000
```

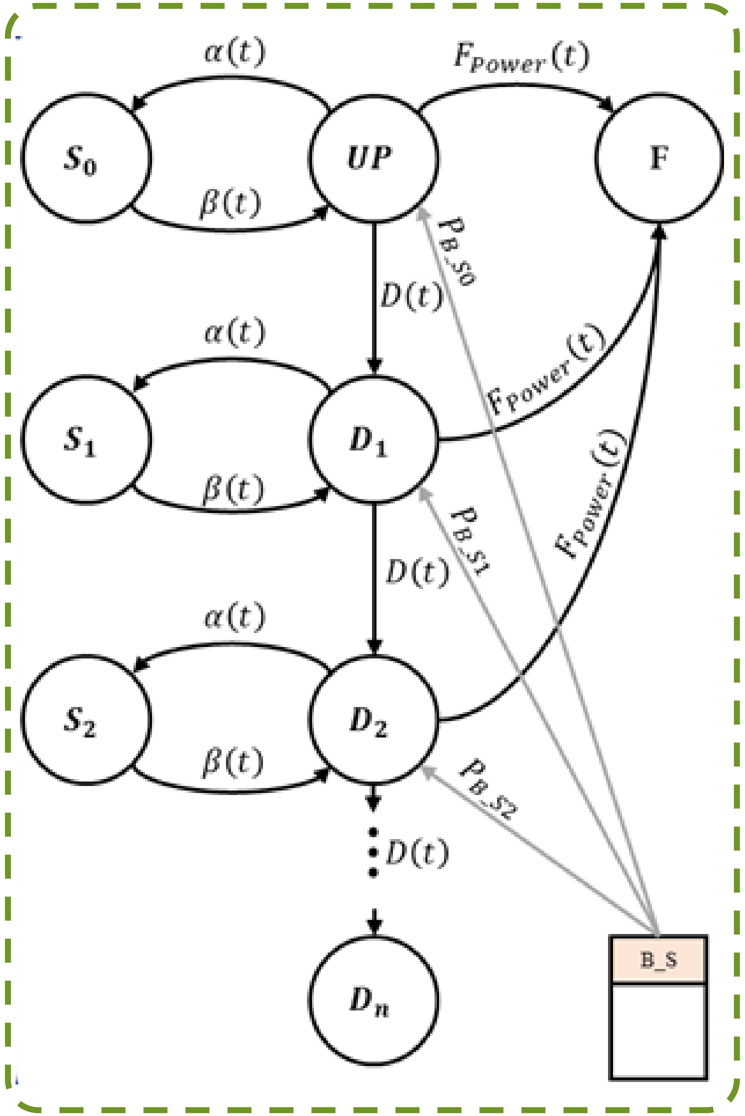


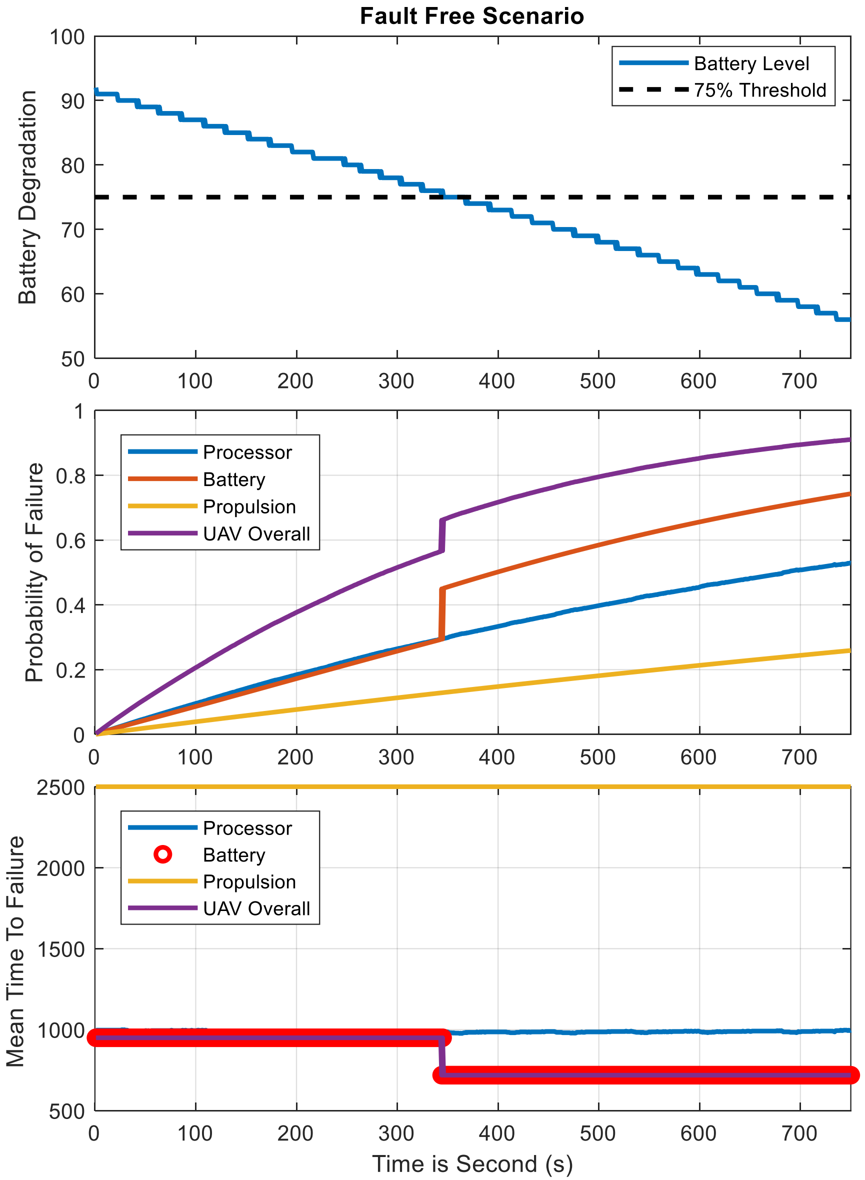

```python
P_Fail, MTTF = Motor_Failure_Risk_Calc([0,1,1,1,1,1], 'PNPNPN', 0.001, 100)

print(P_Fail)

print(MTTF)
```

Battery System

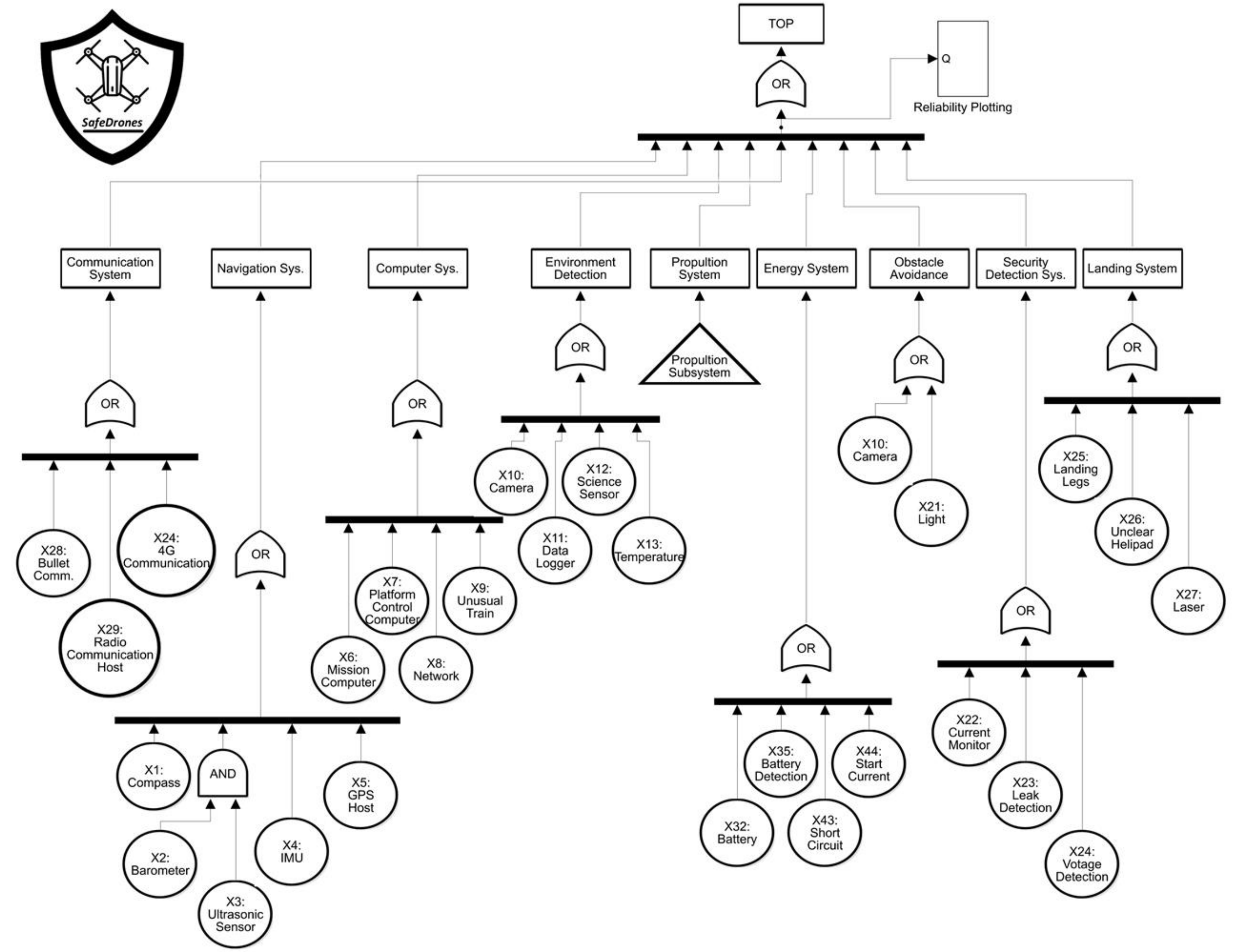
27

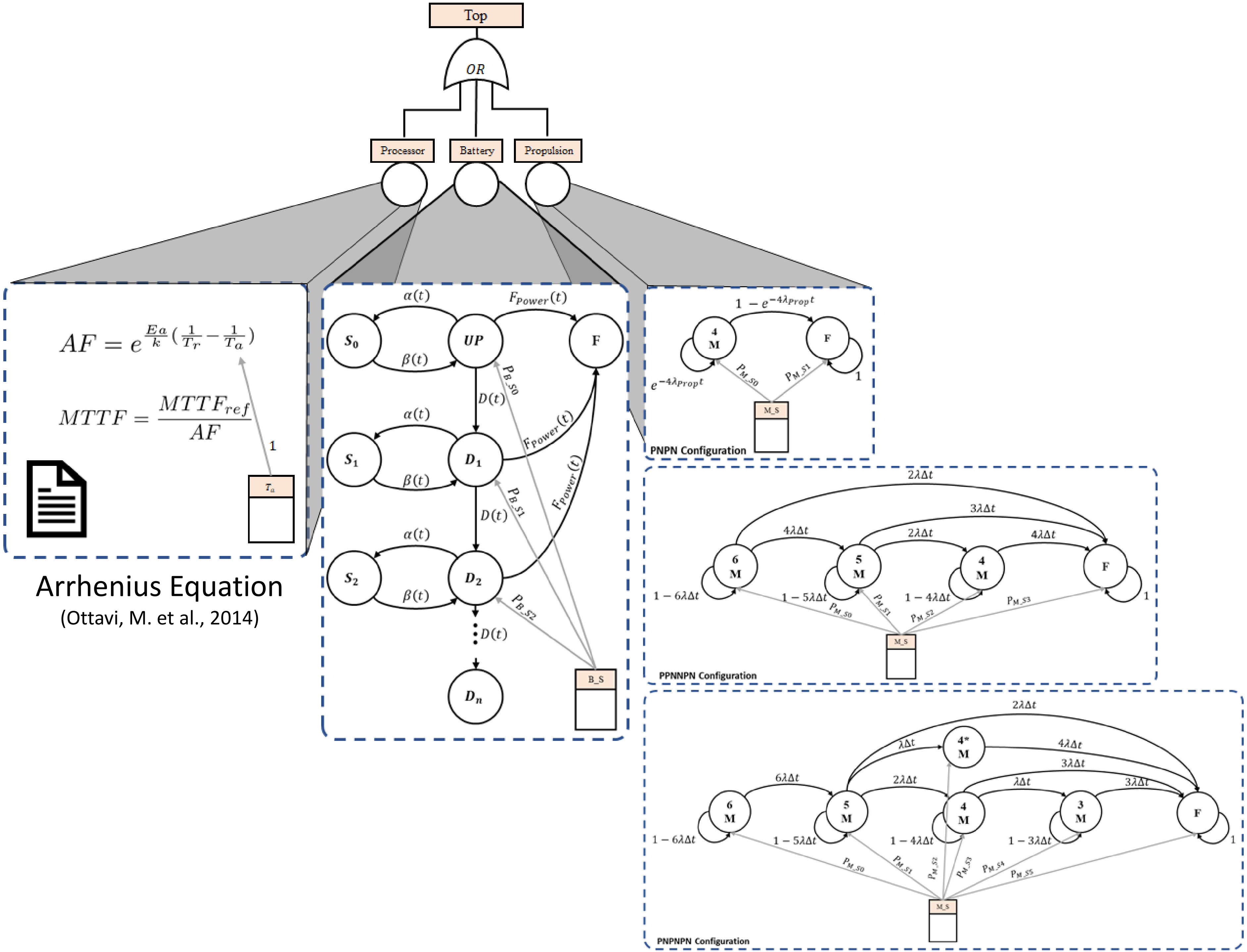
Battery System Degradation and Failure





Kabir, S., Aslansefat, K., Sorokos, I., Papadopoulos, Y., & Gheraibia, Y. (2019, October). A conceptual framework to incorporate complex basic events in HiP-HOPS. In *International Symposium on Model-Based Safety and Assessment* (pp. 109-124). Springer.

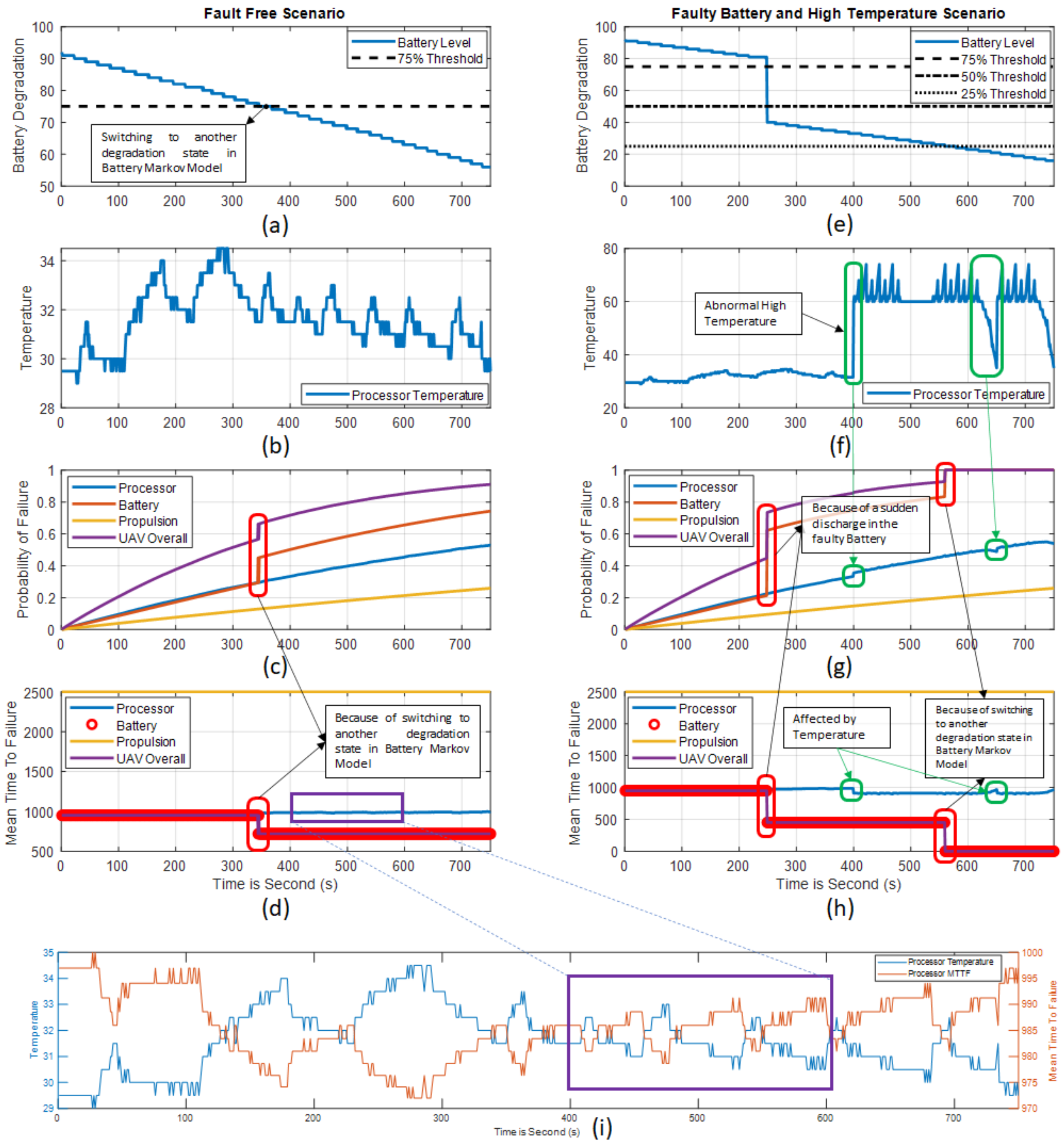

SafeDrones
TOP
OR
Q
Reliability Plotting
Communication System
Navigation Sys.
Computer Sys.
Environment Detection
Propultion System
Energy System
Obstacle Avoidance
Security Detection Sys.
Landing System
OR
Propultion Subsystem
X28: Bullet Comm.
X24: 4G Communication
X29: Radio Communication Host
X1: Compass
AND
X2: Barometer
X3: Ultrasonic Sensor
X4: IMU
X5: GPS Host
X6: Mission Computer
X7: Platform Control Computer
X8: Network
X9: Unusual Train
X10: Camera
X11: Data Logger
X12: Science Sensor
X13: Temperature
X32: Battery
X35: Battery Detection
X43: Short Circuit
X44: Start Current
X10: Camera
X21: Light
X22: Current Monitor
X23: Leak Detection
X24: Votage Detection
X25: Landing Legs
X26: Unclear Helipad
X27: Laser



Arrhenius Equation

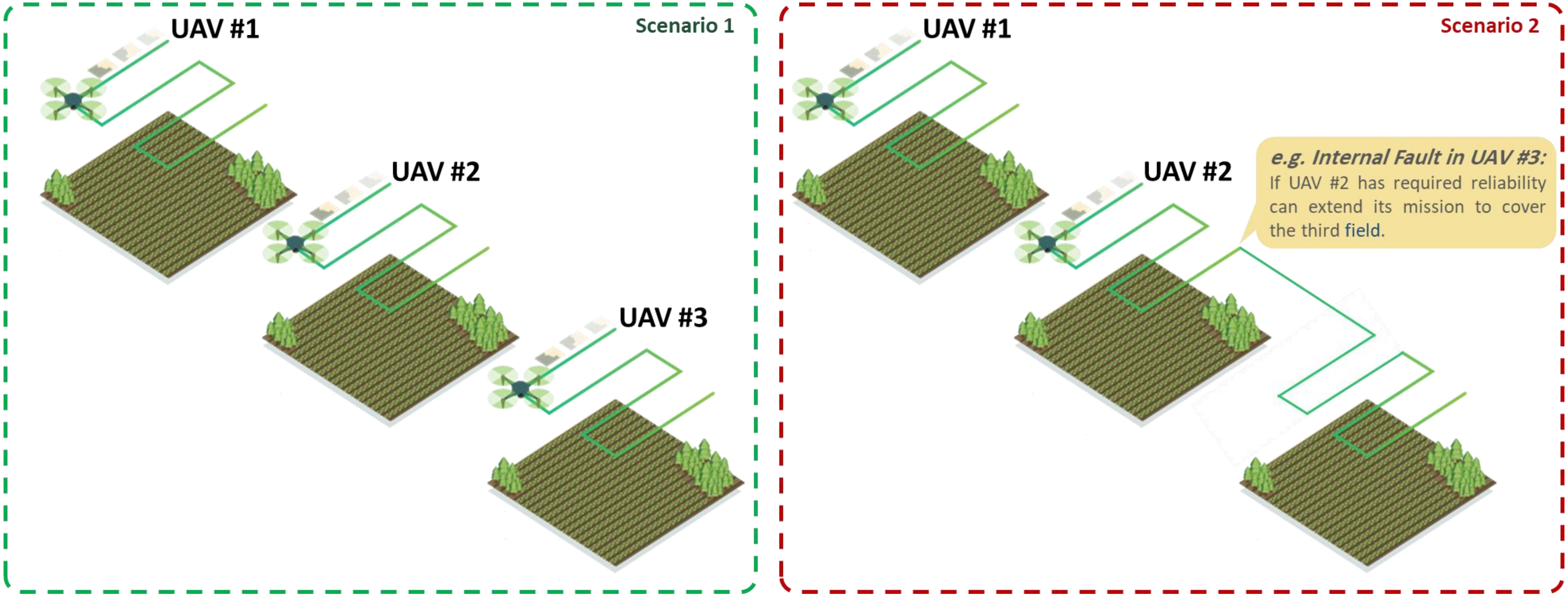
(Ottavi, M. et al., 2014)

Parameters	Description	Values
Motor parameters		
MC	Motor Configuration	PNPN (P: positive clockwise direction, N: negative anti-clockwise direction)
Motor λ	Motor failure rate	0.001
Battery parameters		
Battery λ	Battery failure rate	0.0001
D	Battery degradation rate	0.0064
α	Battery usage rate	0.008
β	Battery inactivity rate	0.007
Processor parameters		
u	Utilization	1
$MTTF_{ref}$	Reference MTTF	1000 hours
E_a	Boltzmann constant	8.617E-05
k	Activation energy	0.3 electron-volts
T_r	Reference temperature	29° C


Fault Free Scenario
Faulty Battery and High Temperature Scenario
Battery Degradation
Battery Level
75% Threshold
50% Threshold
25% Threshold
Switching to another degradation state in Battery Markov Model
(a)
(e)
Temperature
Processor Temperature
Abnormal High Temperature
(b)
(f)
Probability of Failure
Processor
Battery
Propulsion
UAV Overall
Because of a sudden discharge in the faulty Battery
(c)
(g)
Mean Time To Failure
Because of switching to another degradation state in Battery Markov Model
Affected by Temperature
Time is Second (s)
(d)
(h)
Processor Temperature
Processor MTTF
Mean Time To Failure
Time is Second (s)
(i)

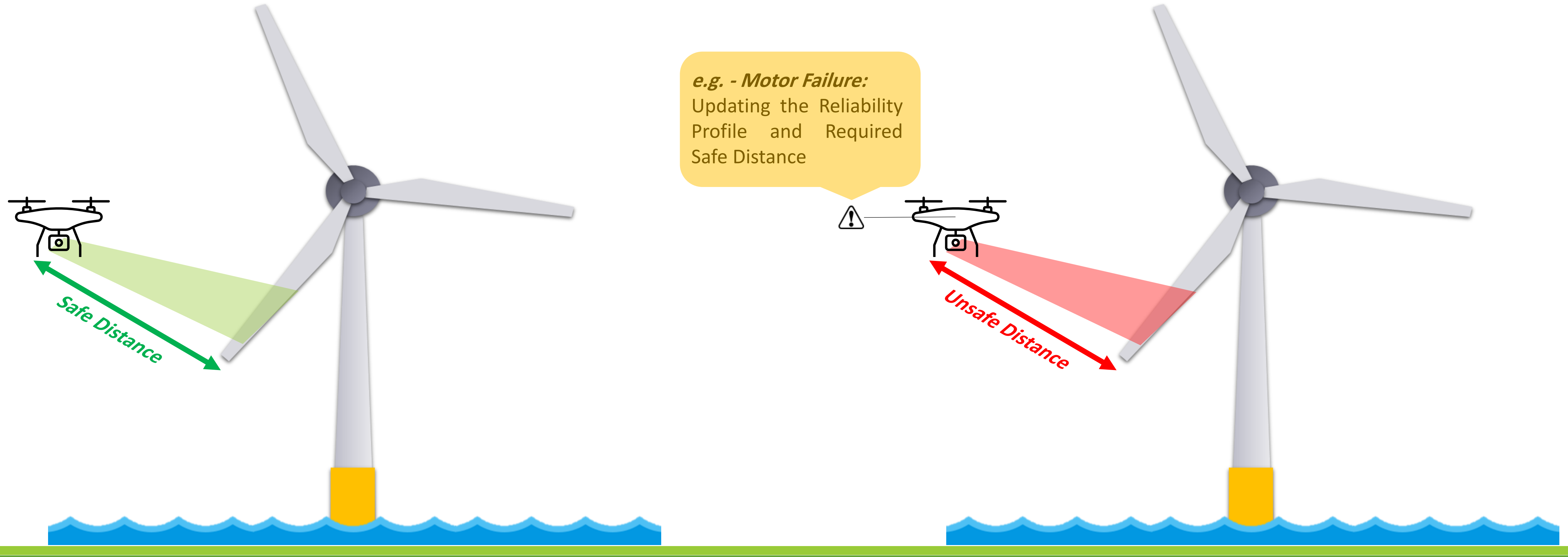
Application of SafeDrones for Multi-robot Precision Agriculture

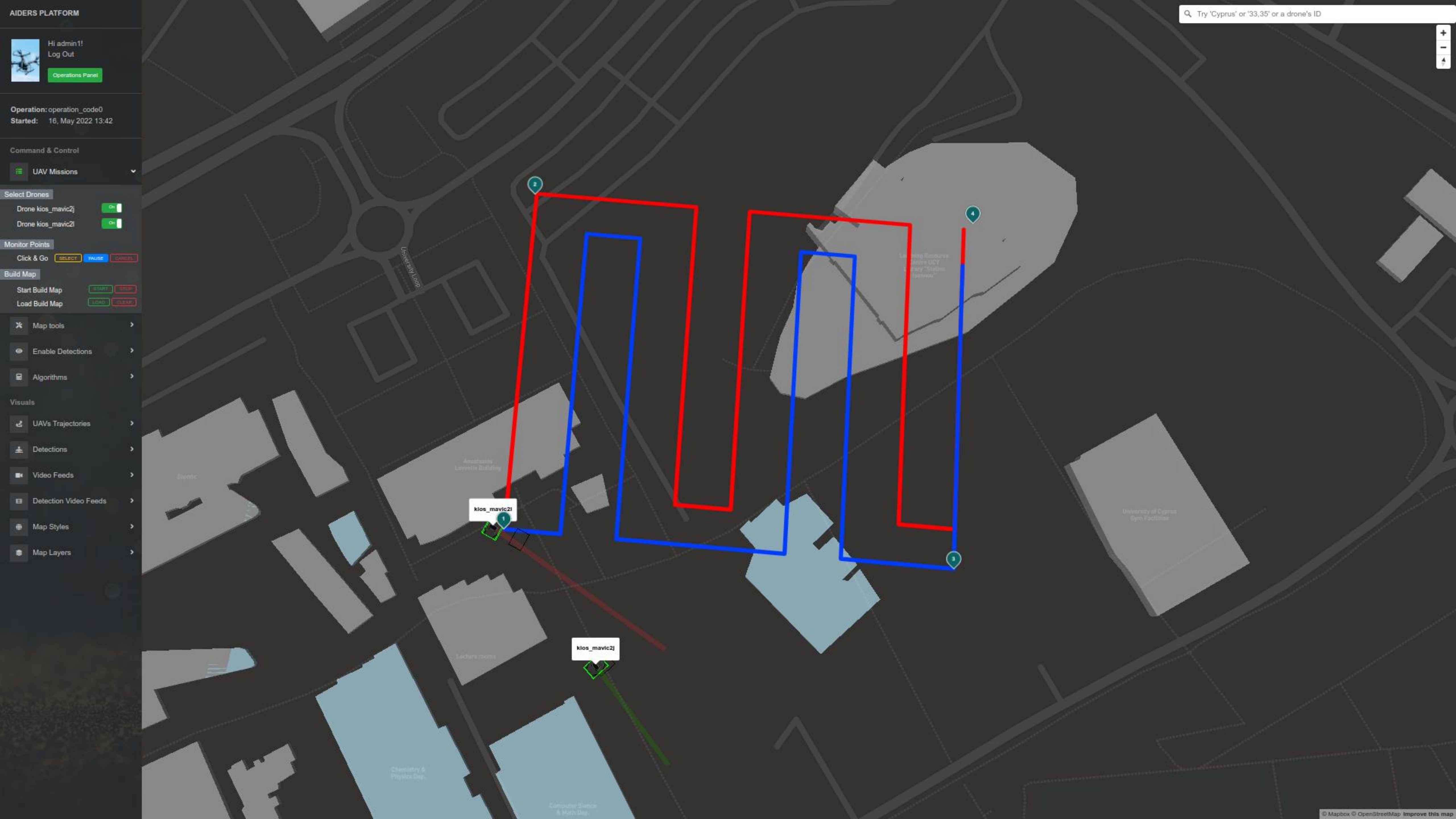
Consider a scenario in which three UAVs are tasked to scan three fields in parallel when an internal fault occurs in UAV #3. Although it does not cause immediate failure, SafeDrones re-evaluates the reliability at runtime and determines it increases the risk above a dangerous threshold, so in order to reduce the risk of collision or spraying out of bounds, UAV #3 activates a fail-safe mechanism and returns to base. If UAV #2 has required availability, its mission can then be updated to cover the third field.



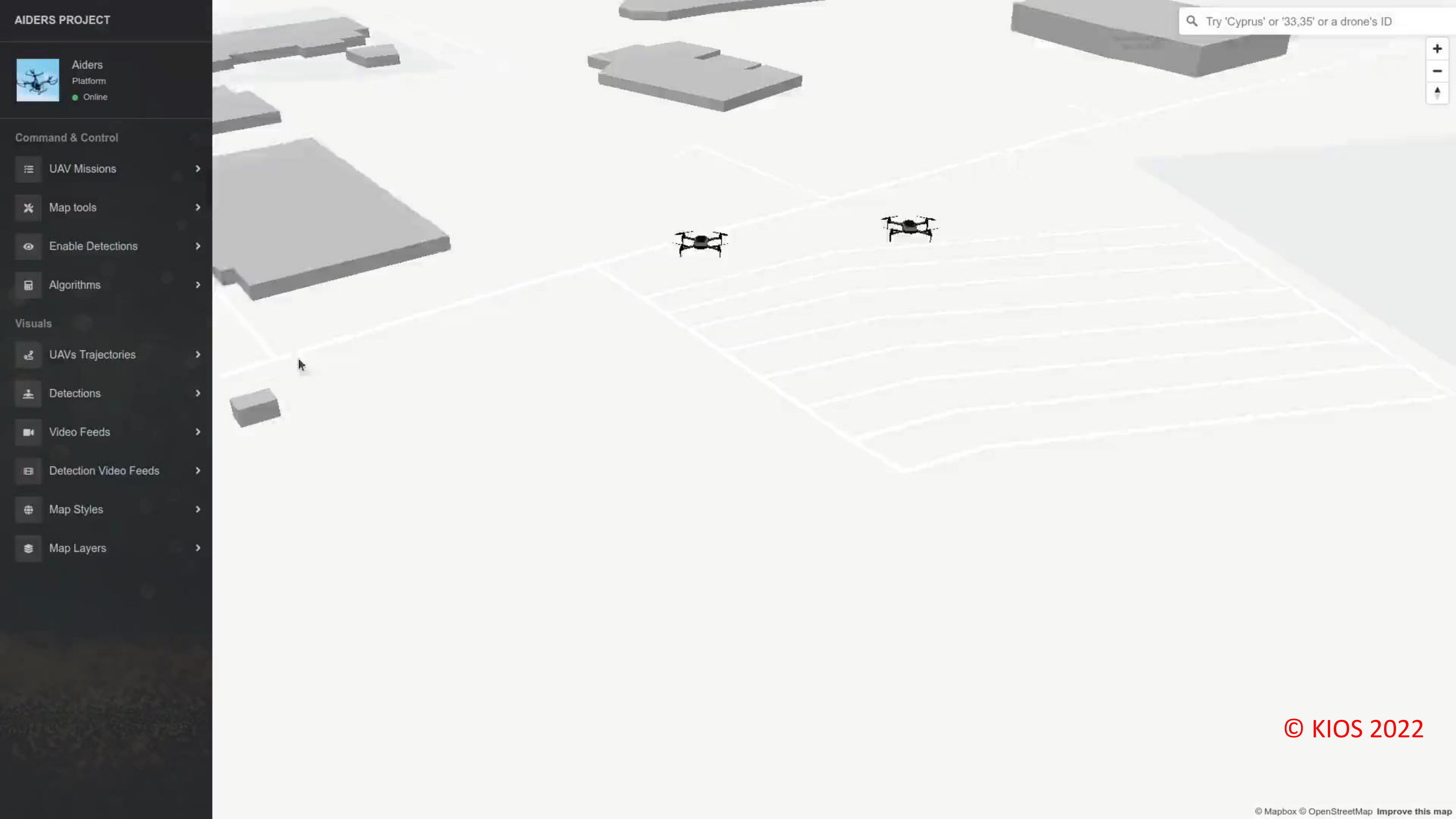
Application of SafeDrones for Offshore Wind Turbine Blade Inspection

Considering the widely variable wind speeds encountered, a fault in the UAV that reduces controllability risks collision with a blade, causing damage to both UAV and wind turbine. The SafeDrones approach allows us to assess risk in real-time in response to the occurrence of faults by providing a runtime evaluation of reliability. Using this information, the drone can adapt its behaviour accordingly, e.g. by increasing safe distance to reduce risk of collision.




AIDERS PLATFORM
Hi admin1!
Log Out
Operations Panel
Operation: operation_code0
Started: 16, May 2022 13:42
Command & Control
UAV Missions
Select Drones
Drone kios_mavic2j
Drone kios_mavic2l
Monitor Points
Click & Go
SELECT
PAUSE
CANCEL
Build Map
Start Build Map
START
STOP
Load Build Map
LOAD
CLEAR
Map tools
Enable Detections
Algorithms
Visuals
UAVs Trajectories
Detections
Video Feeds
Detection Video Feeds
Map Styles
Map Layers
Try 'Cyprus' or '33,35' or a drone's ID
kios_mavic2l
kios_mavic2j
© Mapbox © OpenStreetMap Improve this map


AIDERS PLATFORM
Hi admin1!
Log Out
Operations Panel
Operation: operation_code0
Started: 16, May 2022 13:42
Command & Control
UAV Missions
Select Drones
Drone kios_mavic2j
Drone kios_mavic2l
Monitor Points
Click & Go
SELECT
PAUSE
CANCEL
Build Map
Start Build Map
START
STOP
Load Build Map
LOAD
CLEAR
Map tools
Enable Detections
Algorithms
Visuals
UAVs Trajectories
Detections
Video Feeds
Detection Video Feeds
Map Styles
Map Layers
Try 'Cyprus' or '33,35' or a drone's ID
kios_mavic2l
kios_mavic2j
University Loop
© Mapbox © OpenStreetMap Improve this map


AIDERS PROJECT
Aiders
Platform
Online
Command & Control
UAV Missions
Map tools
Enable Detections
Algorithms
Visuals
UAVs Trajectories
Detections
Video Feeds
Detection Video Feeds
Map Styles
Map Layers
Try 'Cyprus' or '33,35' or a drone's ID
© Mapbox © OpenStreetMap Improve this map

Conclusion

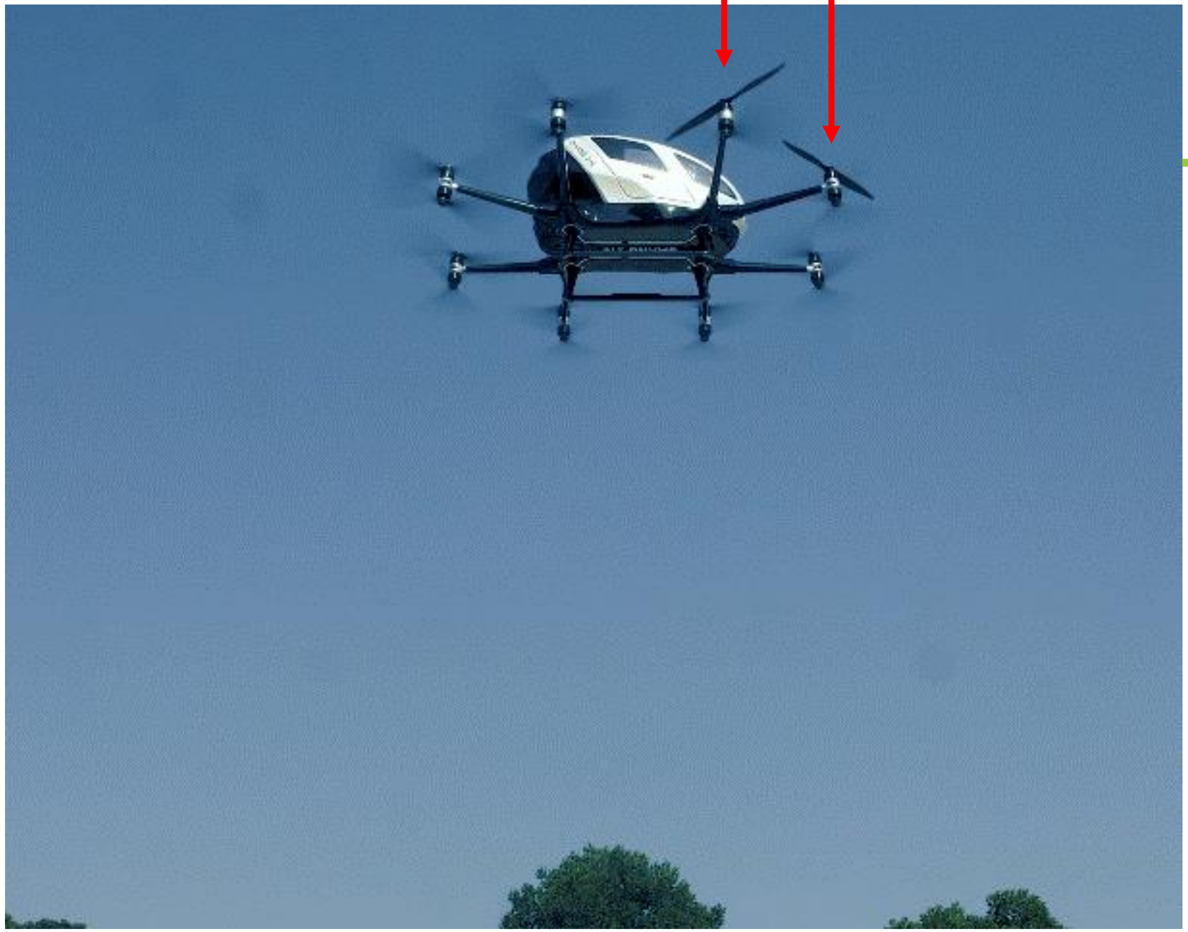
- To help address the problems of UAV reliability and risk assessment, particularly at runtime where operational and environmental factors are hard to predict, the SafeDrones reliability modelling approach has been proposed.

- It employs a combination of FTA with CBEs to support real-time reliability evaluation as a prototype of the EDDI concept.

- It introduces a novel symptoms layer in Fault Tree Analysis to integrate it with runtime monitoring data.

- To illustrate SafeDrones, we applied it to a power network inspection use case to show how real-time reliability evaluation can be used to anticipate imminent failures and prevent accidents by recommending appropriate responses.

Future Works



DDI

Environment Information
e.g., Wind Speed and Direction

SafeDrones

Updating Reliability Profile

ConSerts

Providing Safety Guarantees

Final Decisions
e.g., Aborting mission and Emergency Landing

References

[1] Trivedi, K., & Bobbio, A. (2017). Phase-Type Expansion. In Reliability and Availability Engineering: Modelling, Analysis, and Applications (pp. 551-574). Cambridge: Cambridge University Press.

[2] Aslansefat, K., Marques, F., Mendonça, R., & Barata, J. (2019, May). A markov process-based approach for reliability evaluation of the propulsion system in multi-rotor drones. In Doctoral Conference on Computing, Electrical and Industrial Systems (pp. 91-98). Springer.

[3] Kabir, S., Aslansefat, K., Sorokos, I., Papadopoulos, Y., & Gheraibia, Y. (2019, October). A conceptual framework to incorporate complex basic events in HiP-HOPS. In International Symposium on Model-Based Safety and Assessment (pp. 109-124). Springer.

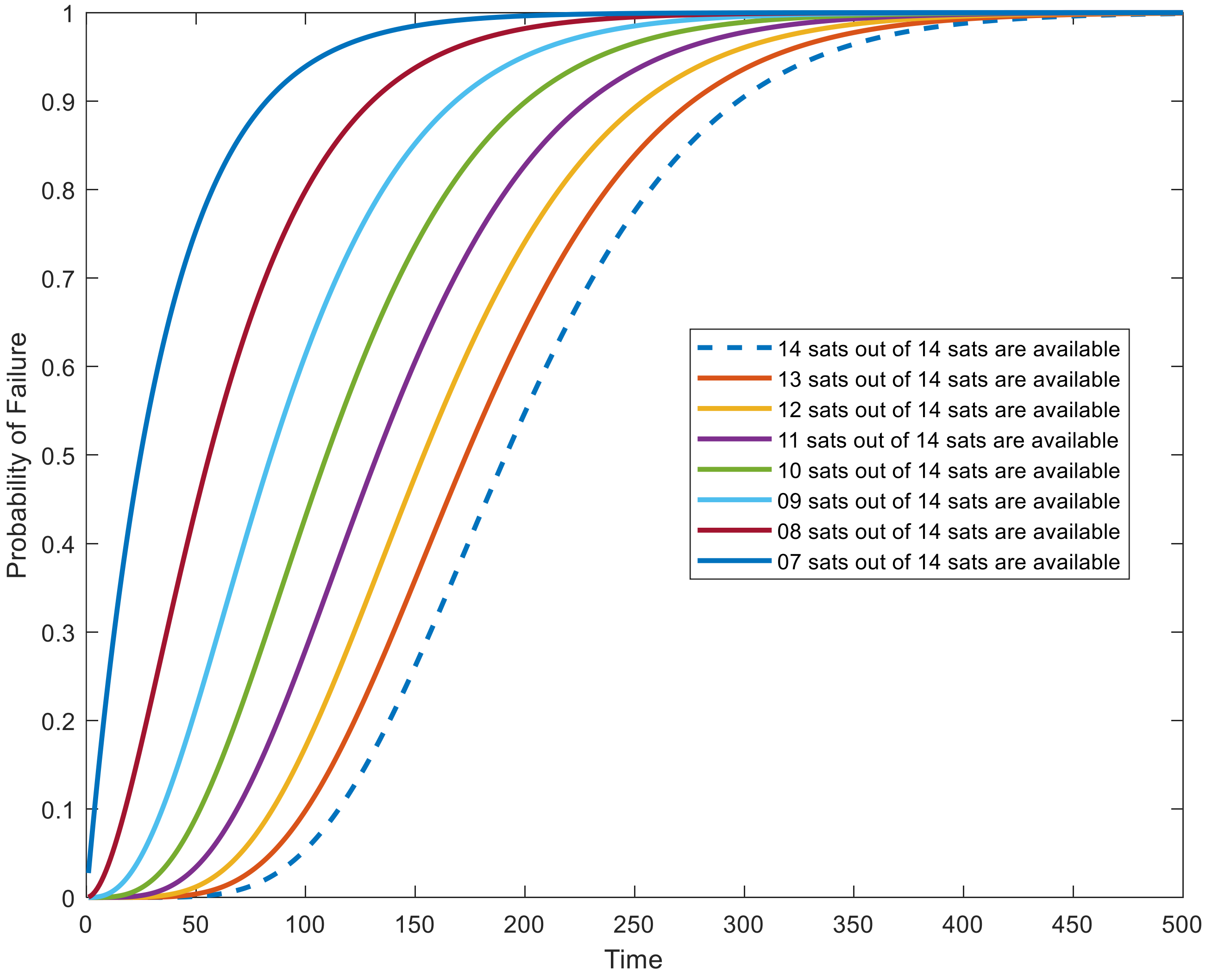
[4] Ottavi, M., Pontarelli, S., Gizopoulos, D., Bolchini, C., Michael, M.K., Anghel, L., Tahoori, M., Paschalis, A., Reviriego, P., Bringmann, O., et al.: Dependable multicore architectures at nanoscale: The view from europe. IEEE Design & Test, 32(2), 17–28 (2014).

[5] Armengaud, E., Schneider, D., Reich, J., Sorokos, I., Papadopoulos, Y., Zeller, M., ... & Kabir, S. (2021, February). DDI: A novel technology and innovation model for dependable, collaborative and autonomous systems. In 2021 Design, Automation & Test in Europe Conference & Exhibition (DATE) (pp. 1626-1631).

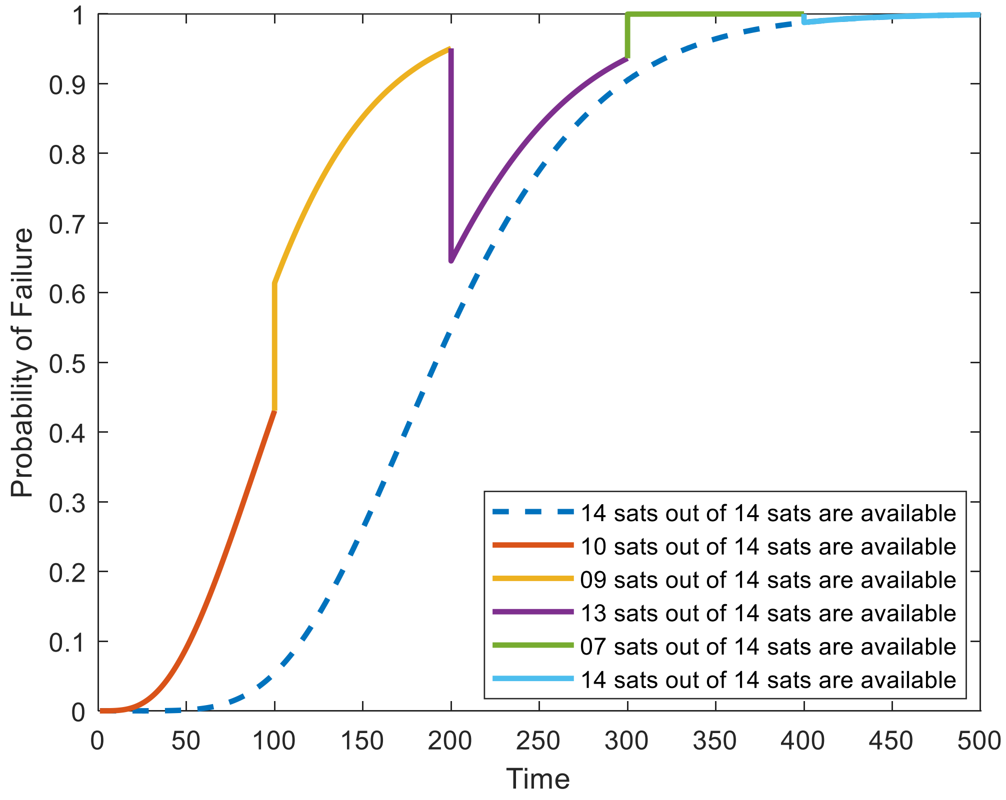
Thanks for Your Attention

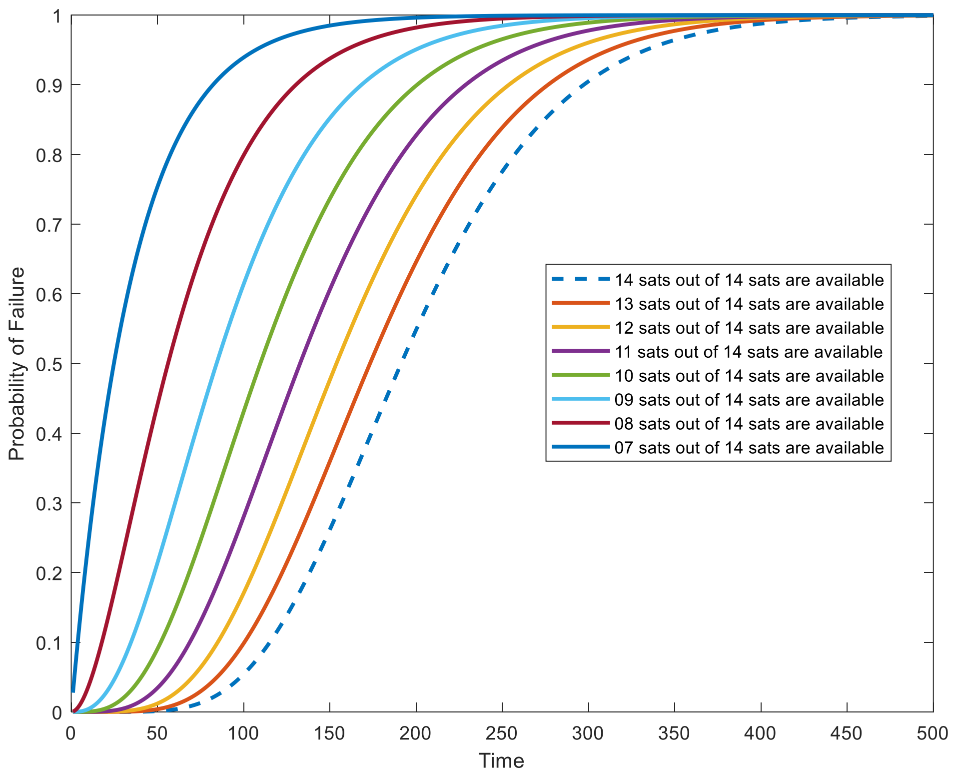
If you have any question, please feel free to ask

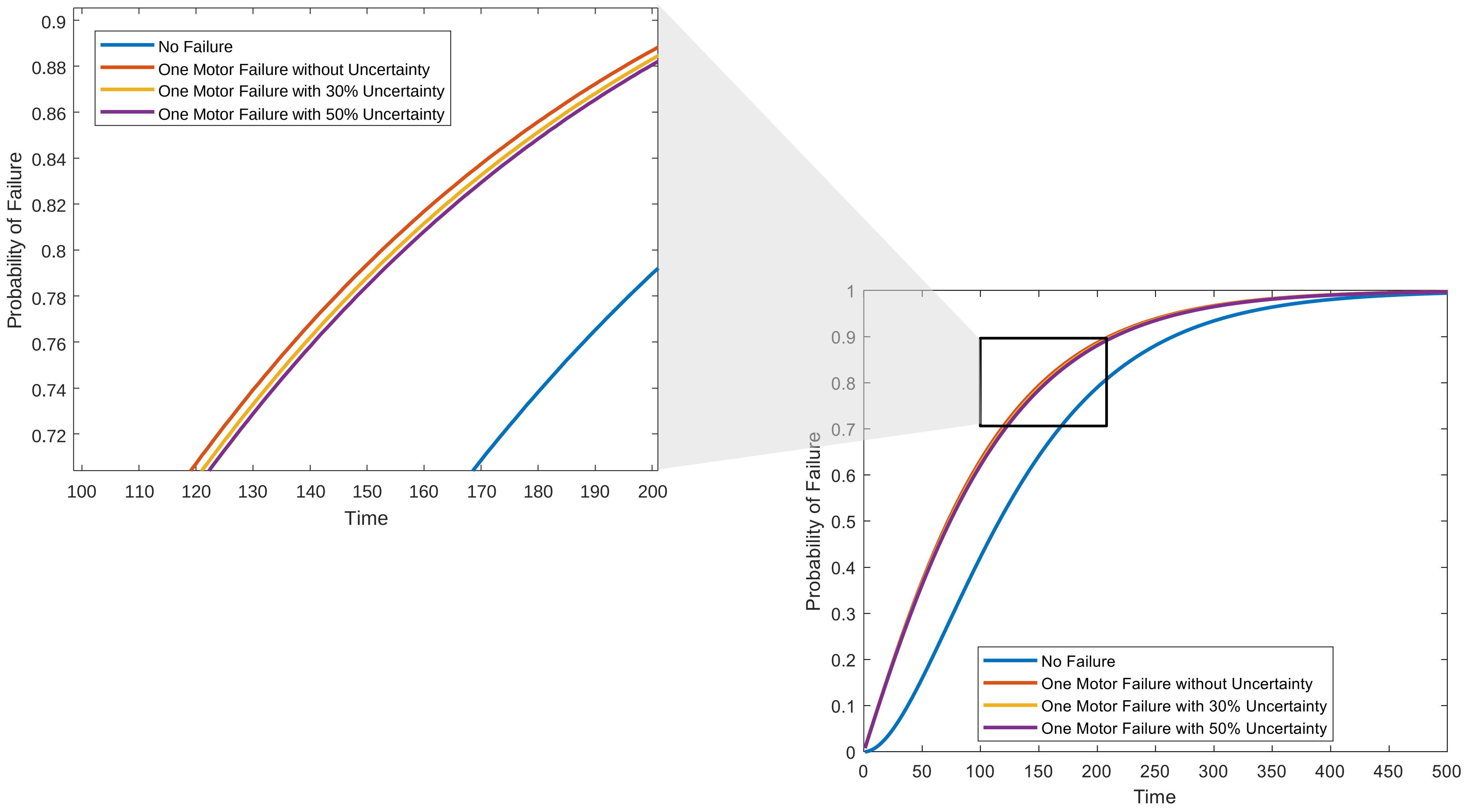
GPS Failure



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Probability of Failure
0
50
100
150
200
250
300
350
400
450
500
Time
14 sats out of 14 sats are available
13 sats out of 14 sats are available
12 sats out of 14 sats are available
11 sats out of 14 sats are available
10 sats out of 14 sats are available
09 sats out of 14 sats are available
08 sats out of 14 sats are available
07 sats out of 14 sats are available


Probability of Failure
Time
14 sats out of 14 sats are available
10 sats out of 14 sats are available
09 sats out of 14 sats are available
13 sats out of 14 sats are available
07 sats out of 14 sats are available
14 sats out of 14 sats are available


Probability of Failure
Time
14 sats out of 14 sats are available
13 sats out of 14 sats are available
12 sats out of 14 sats are available
11 sats out of 14 sats are available
10 sats out of 14 sats are available
09 sats out of 14 sats are available
08 sats out of 14 sats are available
07 sats out of 14 sats are available



No Failure
One Motor Failure without Uncertainty
One Motor Failure with 30% Uncertainty
One Motor Failure with 50% Uncertainty
Probability of Failure
Time