27th annual INCOSE international symposium

Adelaide, Australia

July 15 - 20, 2017

ENGINEERS AUSTRALIA SESA

Model-based design of an autonomous function for responsive satellite operations

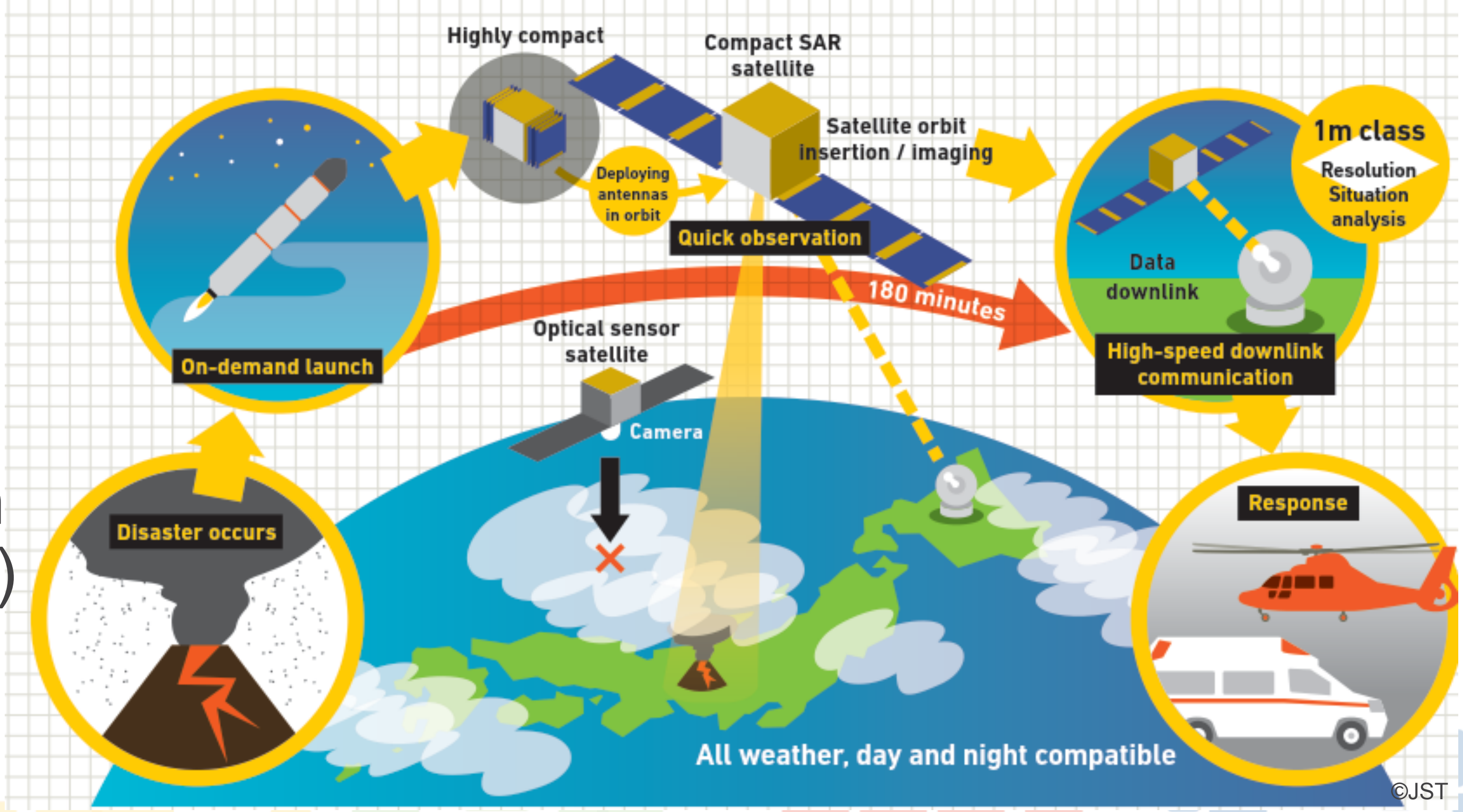
Toshihiro Obata, University of Tokyo

Early Response to the Disaster Needed

2011. 3. 11 Huge Earthquake in Tohoku, Japan

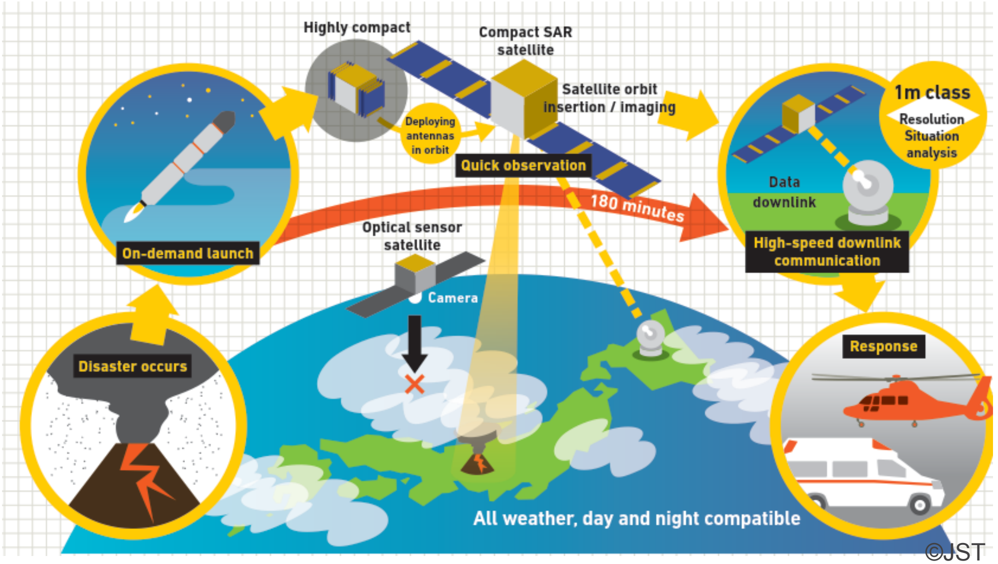
Responsive (On-demand) Satellite

- The program is funded by Japanese government and the satellite will be launched in 2020
- Launch after disaster occurs, observe the affected area and downlink the data within < 3hours
- Autonomous is necessary for initial check of functions and coping with unexpected events (it usually takes at least 3days to observe the earth after launch of the satellite)



Autonomous for Satellite Operation Needed

Responsive mission
(full autonomous operation is expected)

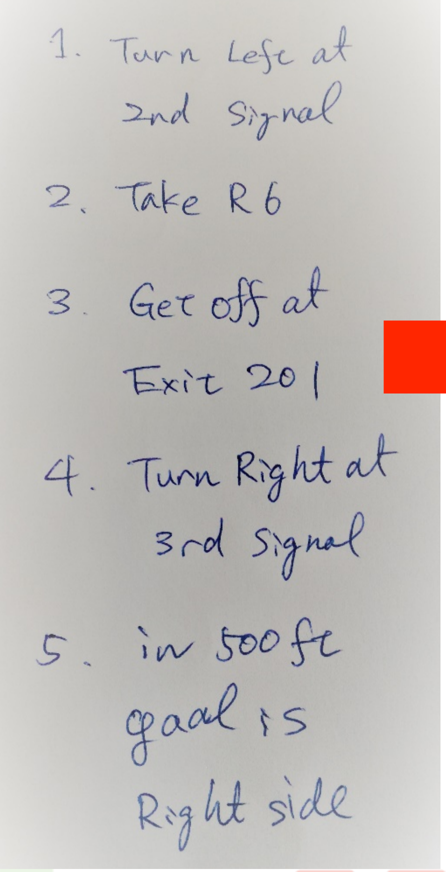


Mega-constellation mission (>900 satellites)

Autonomous Planning : Car Navigation System

- We already don't plan the route by ourselves, but the car navigation system will do instead
- Models of the routes (= maps) enable it
- We expect the same in the satellite operation area
- Good models for the satellite behaviors are necessary

Pre-designed procedures (Old)



Model-based Autonomous Planning (Now)

How Systems Engineering can Contribute?

- Behavior design and verification
  - Behavior is important. We should design and verify it.
- Seamless information transformation
  - Information produced in design phase should used in verifications and operations
- Challenge to the quality
  - Designing and verifying operation procedures need thorough understanding of functions and operational environment
  - University project has always issues about knowledge transfer Knowledge transfer effort can be relaxed, if autonomously operated

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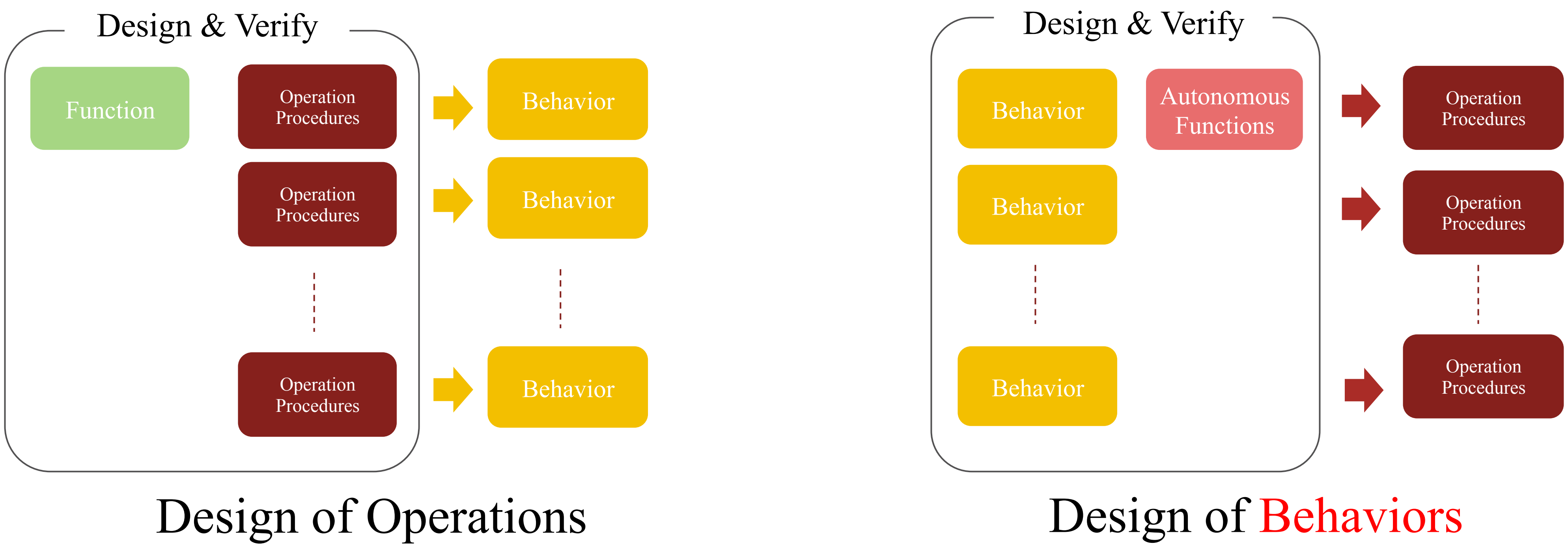
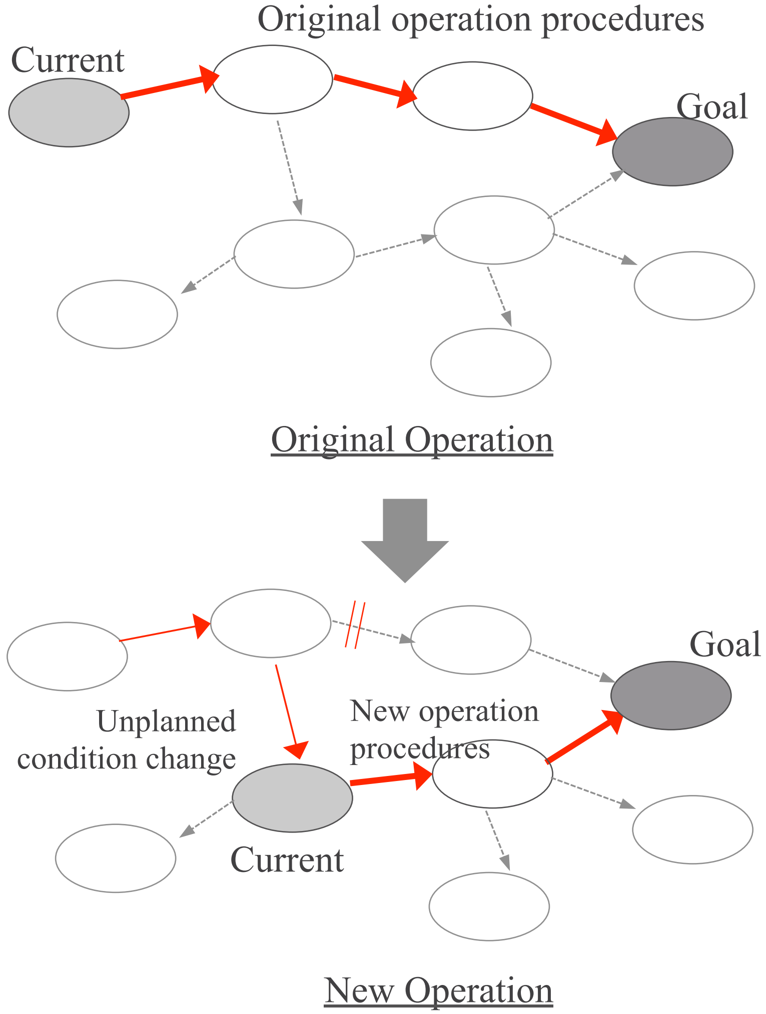
Behavior design and verification

- Behaviors are important. Let’s explicitly design and verify behaviors first, not operation procedures
- Model-based autonomous functions enables this



Model-based Operation

- Goal oriented operations with behavior models (not with procedures)
- Behavior model designed by model-based systems engineering (State Transition Model)
- Search for the path to the goal
- On-board operation commands generations
- Model-based systems engineering and its tool enable this



Items We Have to Make a Model

- State transitions of each functions
  - Including S/Ws, not only H/Ws
  - Including behaviors affected by possible anomalies
- Commands(directions to the functions) and telemetries (monitors) to trigger the state transitions

- Benefit of using models
  - Inherently, these are information derived from design (or requirements / specifications, validated, verified and consistency checked)
  - State transitions for the limited number of functions are necessary
    - The number of the functions is limited to achieve the specific mission goal
    - For our demonstration mission, we modeled 8 sets of state transitions, 23 telemetries and 36 commands

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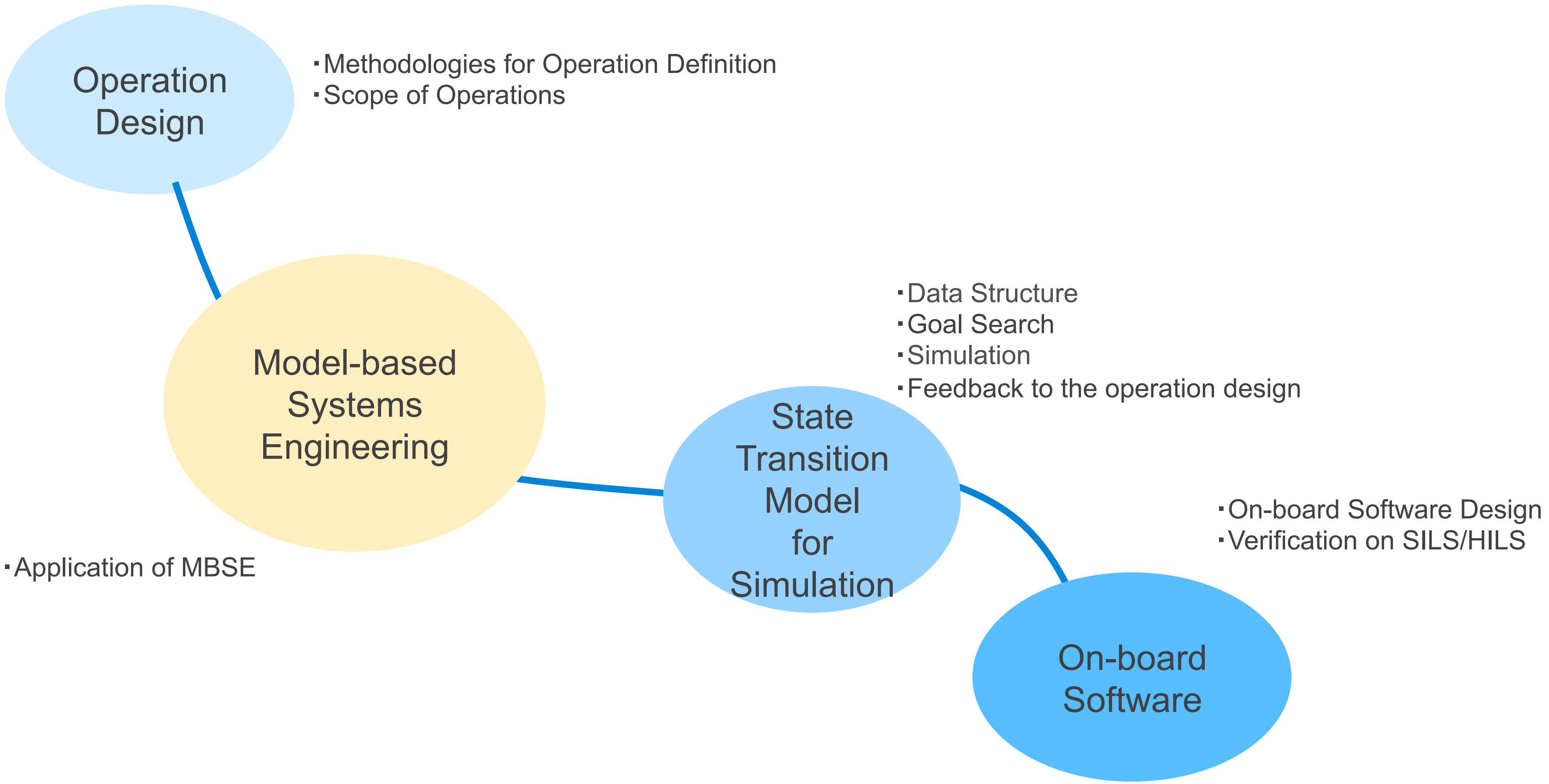
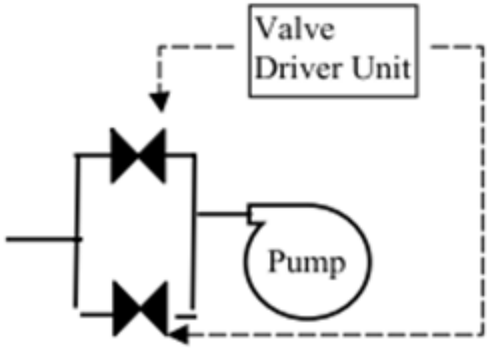
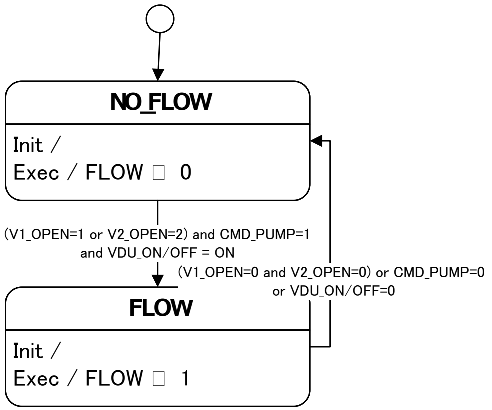
Design Process for Autonomous Operation

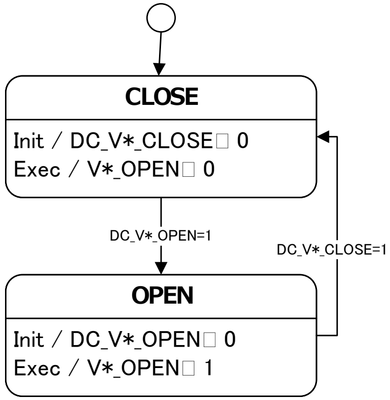


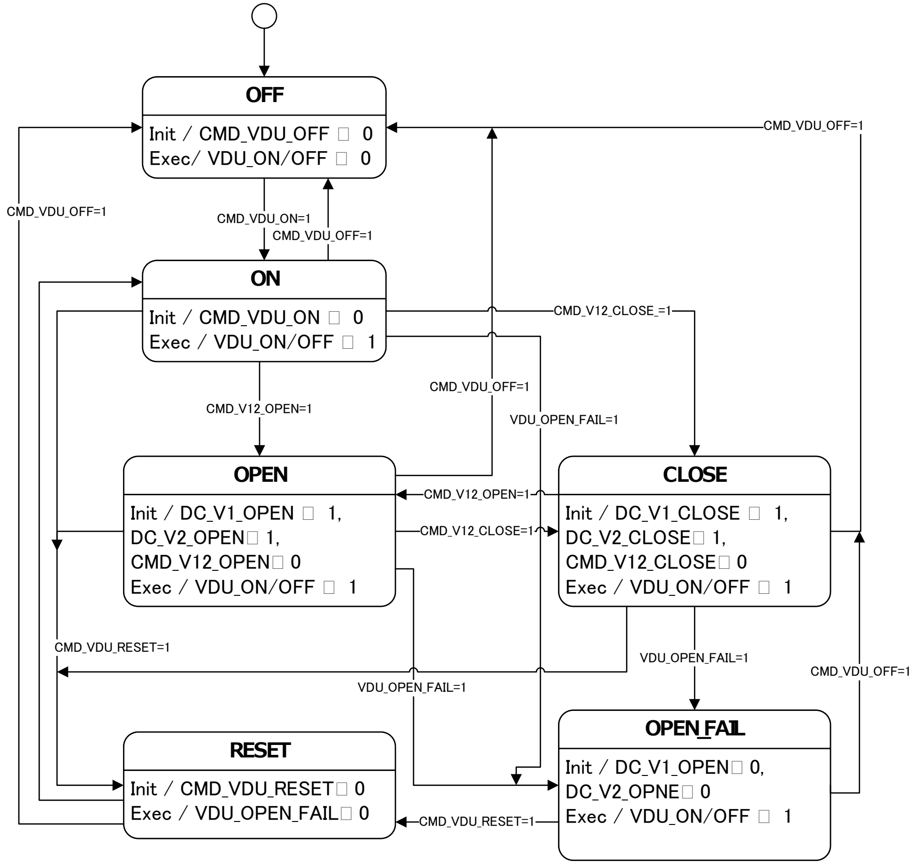
State Transition Model



Kurien and Nayak 2000

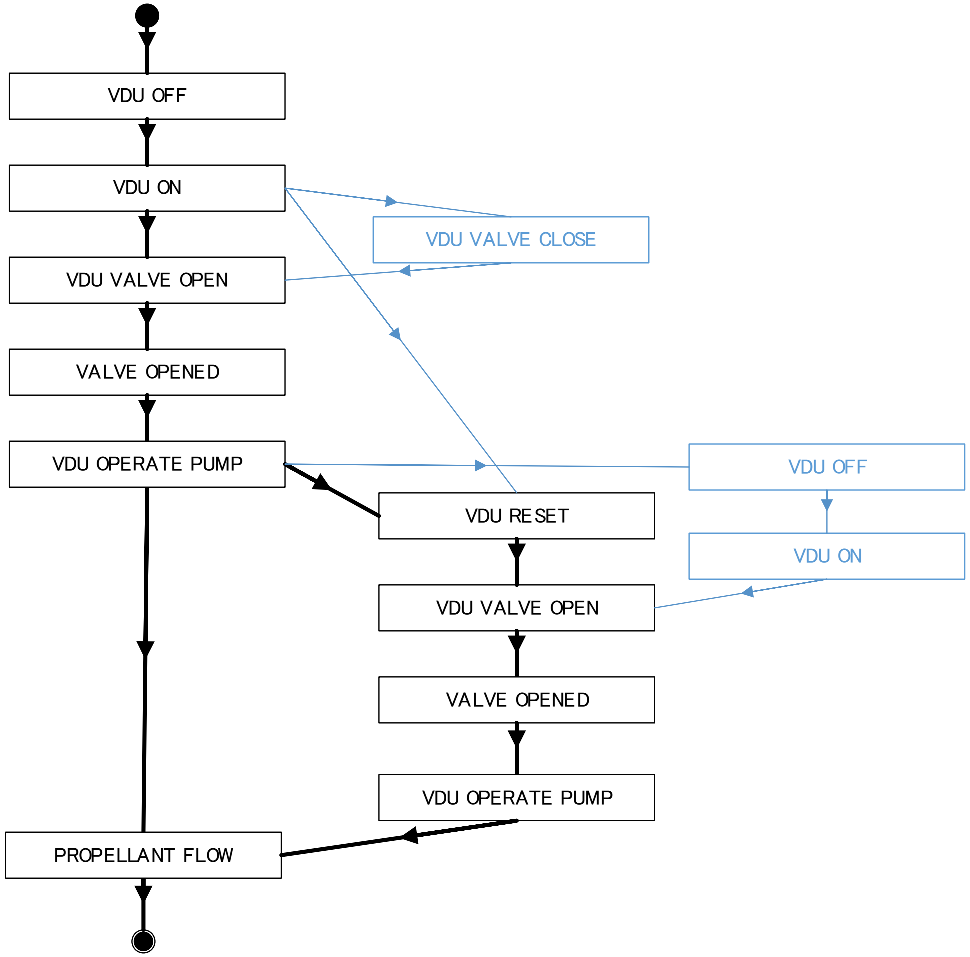






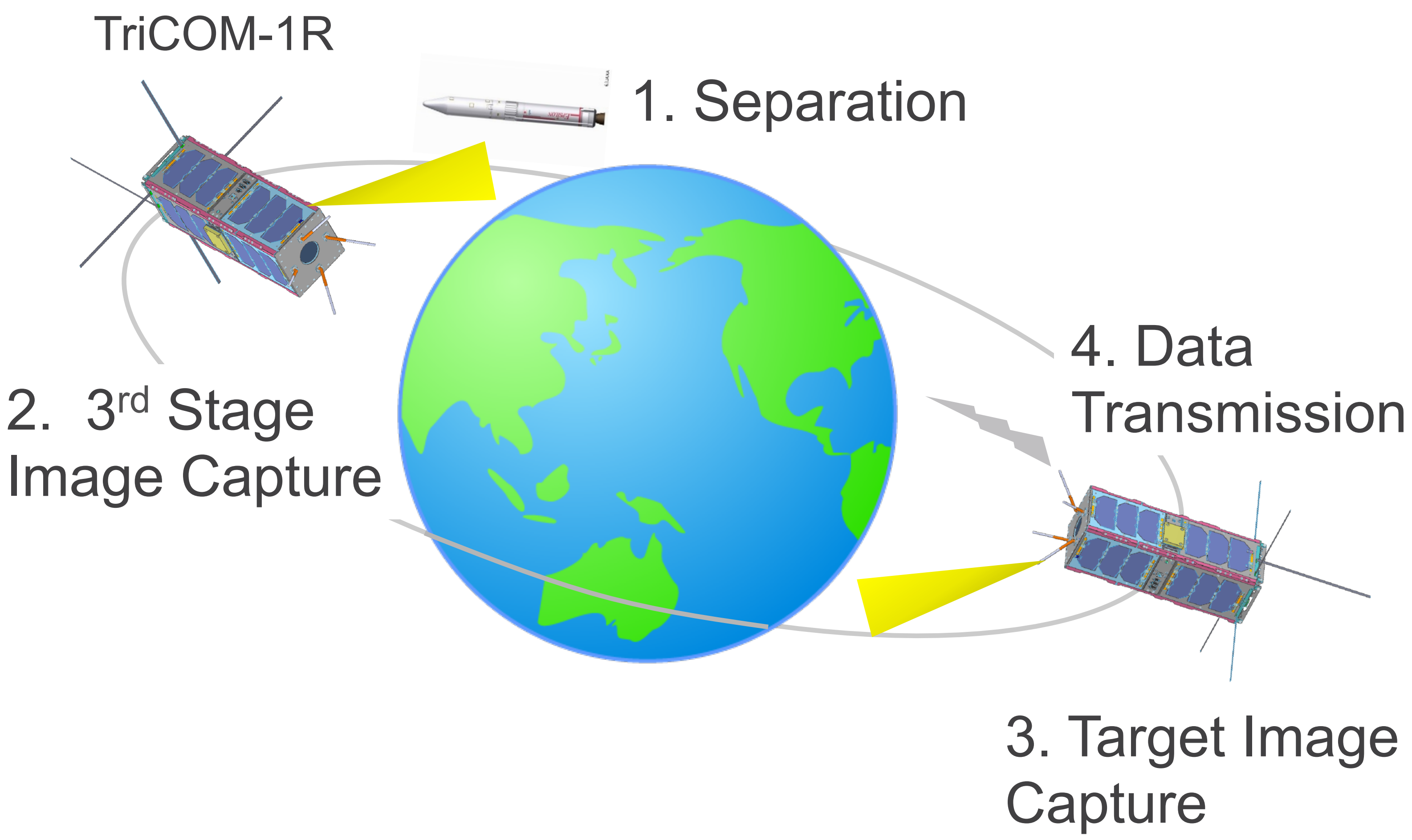
Goal Search Simulation Results

- 6 paths to the goal are generated in total
- Nominal and off-nominal paths
- Autonomous functions use this results to operate satellite against anomalies
- Critical path which there is only way to transit can be represented explicitly



Demonstration

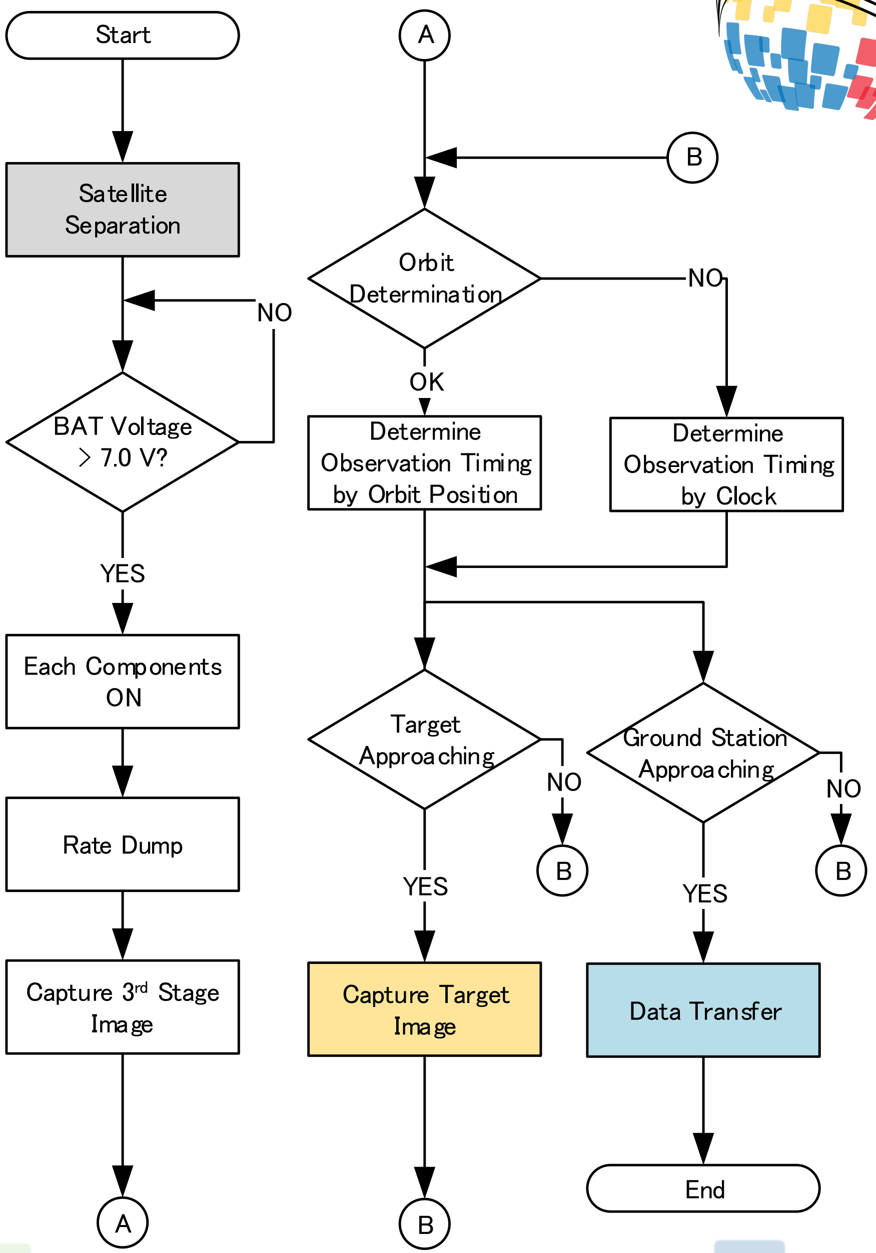
- We have a plan for demonstration within 2017 by cubesat (10x10x30cm, 4kg)
- Capturing images just after the launch without any interaction with human operators



Demonstration (Cont.)

- All activities are done autonomously within 1st orbit cycle (< 90min) against anomalies (like GPSR failure, BAT voltage failure)

- Autonomous functions designed by model-based way control the satellite and achieve the operation flows to the mission goal



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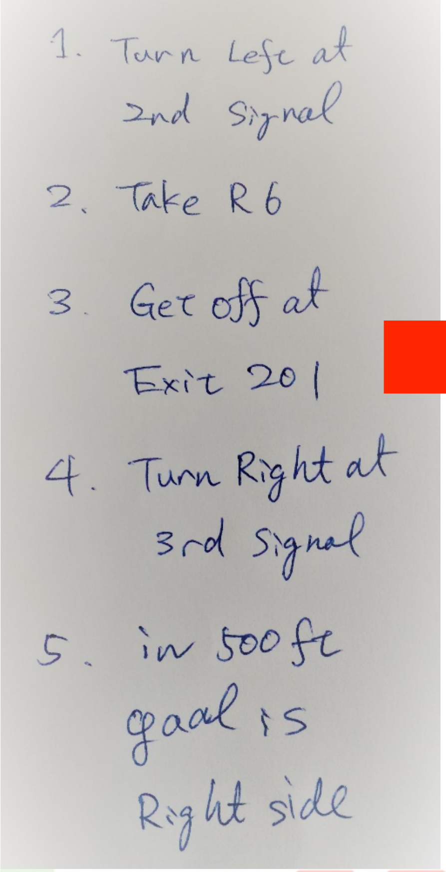
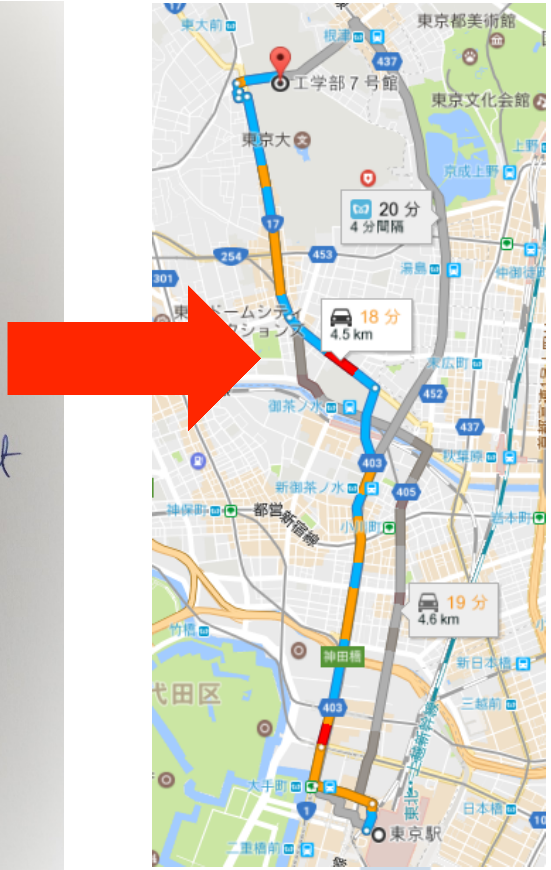
Challenges to the Quality

- Small Satellites Challenges
  - Always challenging quality restrictions
  - Parts, processes, regulations, mission
  - But not so much about operations
- Uber : non-professional drivers can provide an professional transportation service by using model-based planning
  - Even if they do fail to turn signal, it can be accepted
- How about satellite operators?
  - Now, when we fail to send the right command, we have to halt and investigate the situation and make, verify and resend the recovery commands
  - Only experts can handle this type of contingency operations
  - Autonomous operation enables to accept miss-operations

Pre-designed procedures (Old)



Model-based Autonomous Planning (Now)



Conclusion and Future Works

- Need for autonomous operation is emerging and model-based design is suitable for it
- Demonstration on cubesat (2017) and on-demand disaster monitoring satellite (2020)

Acknowledgement

- This work was performed by the University of Tokyo under contract with the Impulsing Paradigm Change through Disruptive Technologies (ImPACT) Program, Cabinet Office, Government of Japan

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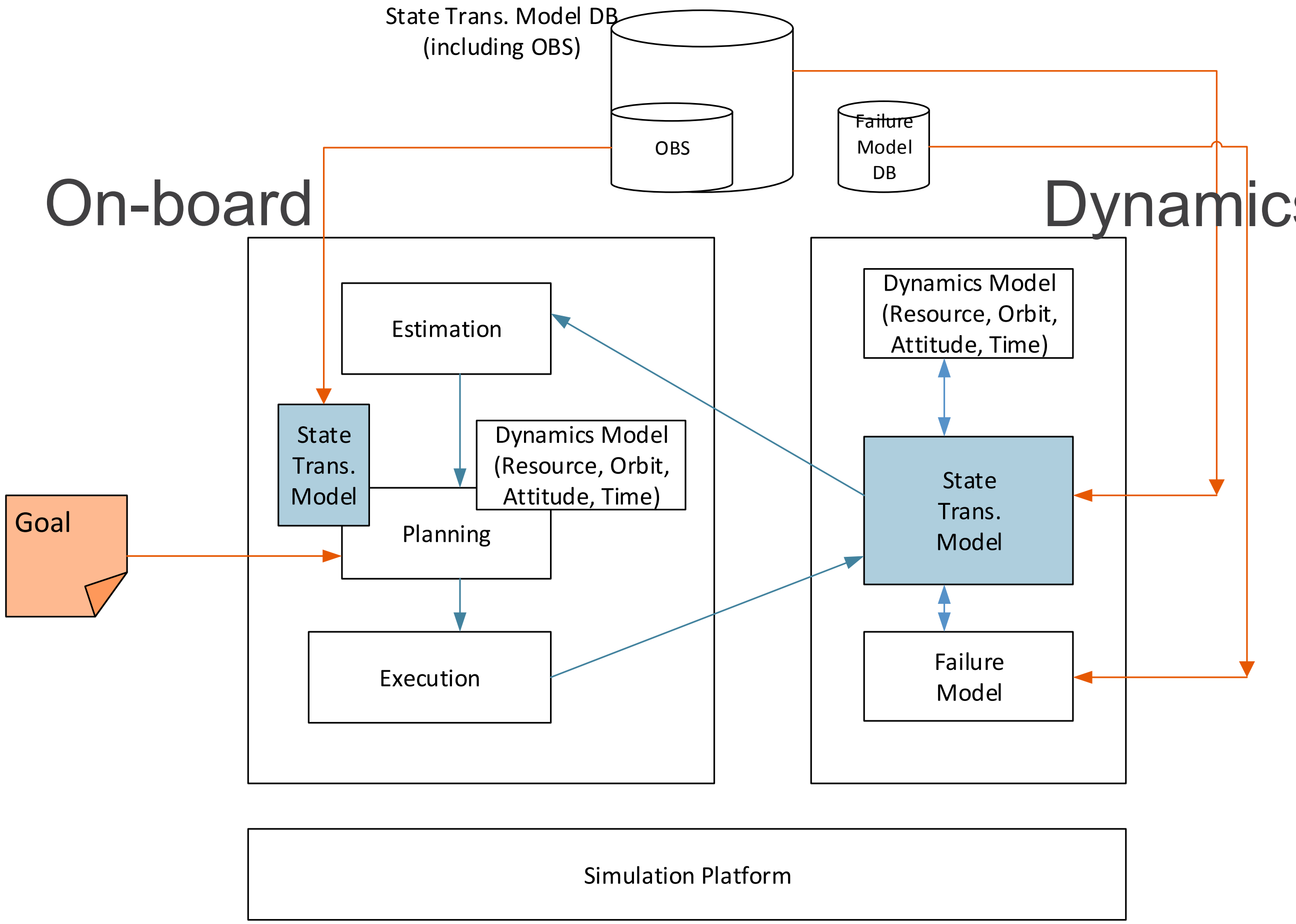
Simulation

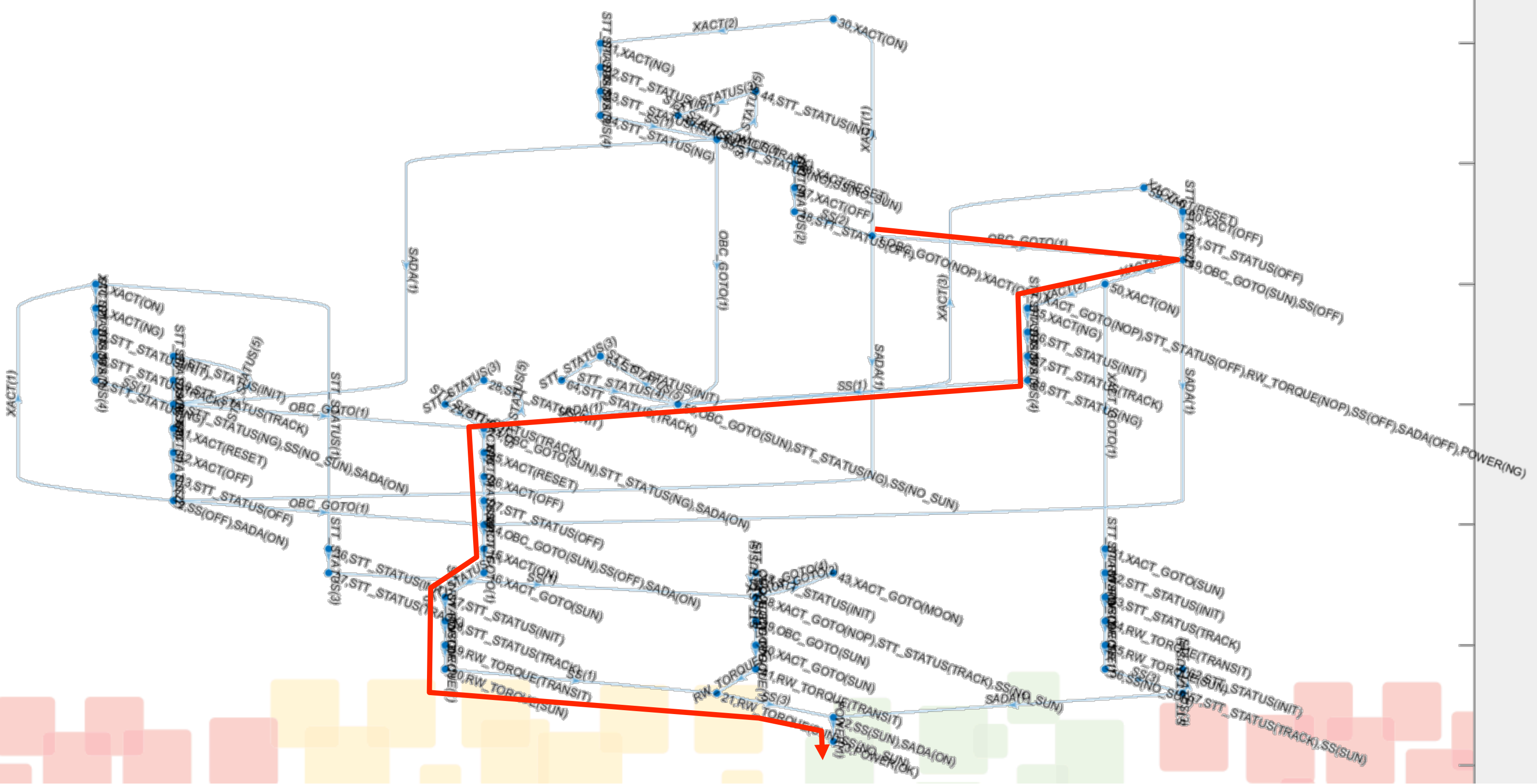
State Transition Data Base
Derived from MBSE tool

- On-board and Dynamics shares same state transition model, however dynamics has more detain model
- Verify the autonomous functions and state transition models
- Evaluate robustness

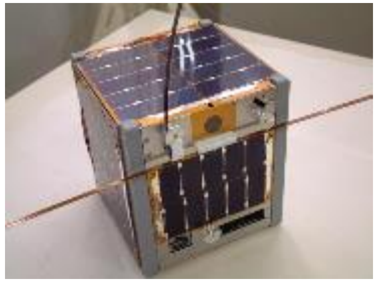


ADCS and EPS Example

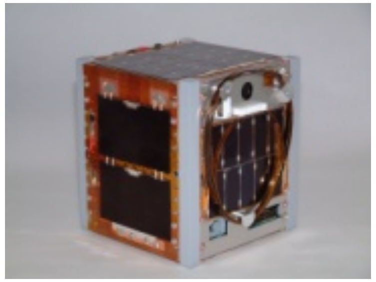
- 8 state transition models(OBC, ADCS OBC, STT, RW, SS, SADA, Power), 11 commands and 21 telemetries
- The given goal is “Sun-point and power generation with solar array orientation” after separation of the satellite
- 44 paths including resetting OBC to recover from ADCS OBC glitch



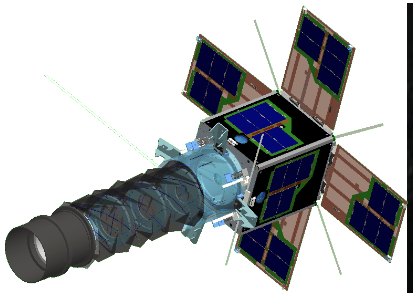
Univ. of Tokyo Small Sats (9 Developed, 8 Launched）



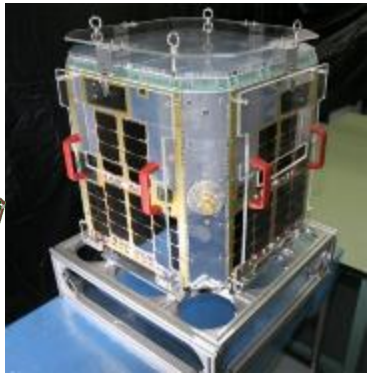
World 1st 1kg Sat
XI-IV(2003）



Tech Demo
XI-V(2005）

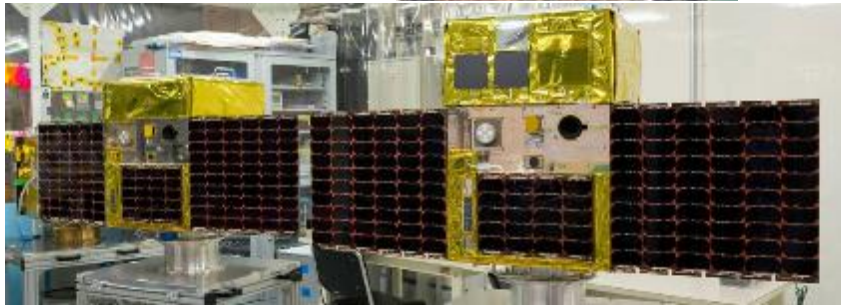


8kg for 30m GSD
PRISM(2009）

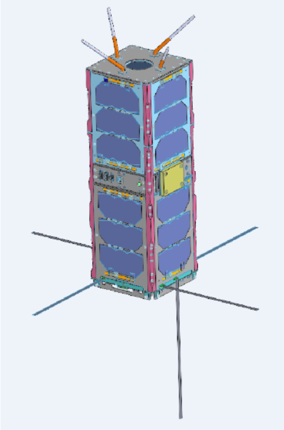


State of the Art
Space Science
Nano-JASMINE
(Waiting for launch）

World 1st Deep
Space Small Sat
PROCYON(2014）

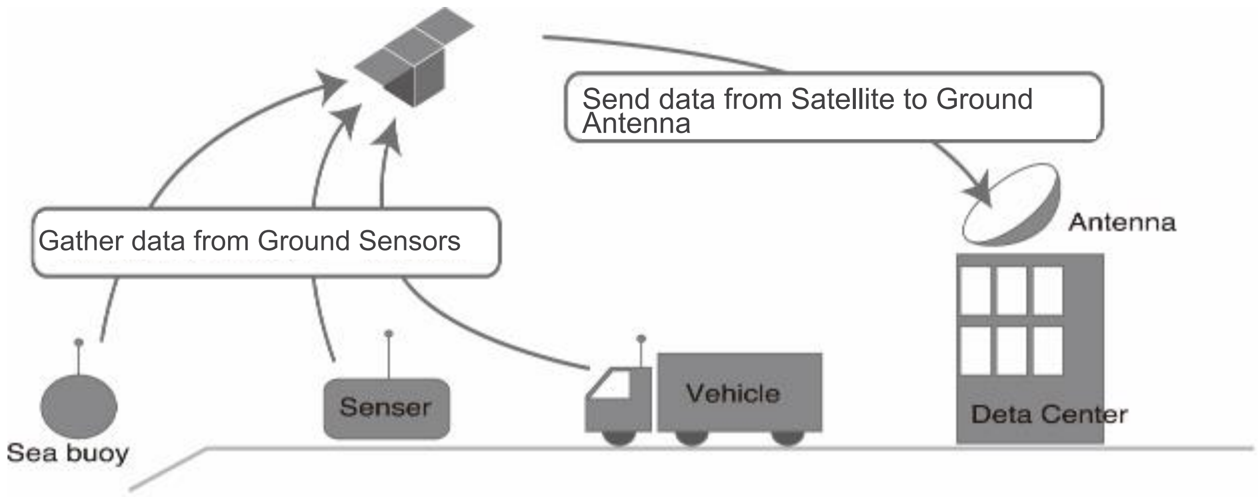


60kg class 6mGSD (2years **for development**）
Hodoyoshi-1 Hodoyoshi 3/4（launched in 2014）



S&F satellite TRICOM-1
(Jan 2017)

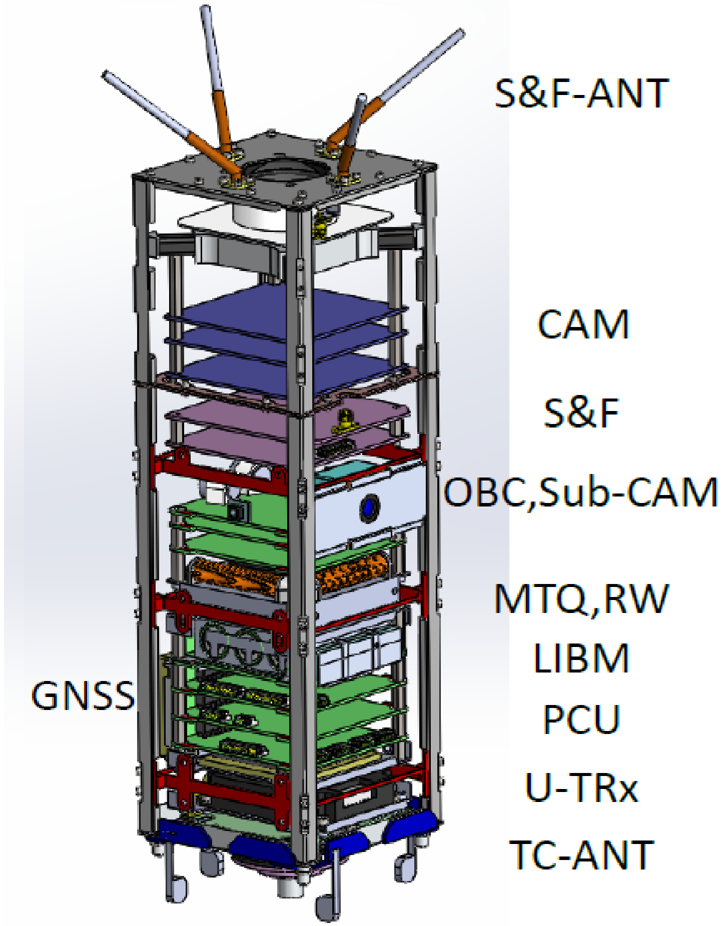
Stored & Forward

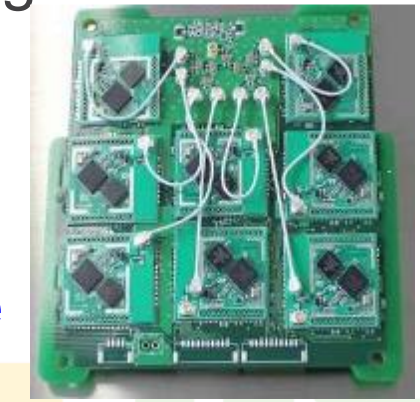


- Ground or buy sensors to measure, satellites to collect data that downlinked to ground stations at low bit rate
- UNISEC-Global is now proposing to build a constellation of cubesats for the mission. Each country/university can contribute with their own satellite and get frequent access of sensor data through the constellation
- Key is ‘what to measure’
  - Water quality, water level, soil, environment(CO_2, gas), car velocity(traffic jam), ship route(oceanic current), ground movement(earthquake)
  - Competitive where no mobile infrastructure, dangerous areas, etc.

3U CubeSat “TriCom-1”

- Store & Forward Test Satellite of University of Tokyo,
  (Launch …. Failed in Sunday)
- Affordable : Cubesat
- No RF license is needed, globally
- Simple protocol
- Less power, good enough data rate (100bps)
- Suitable mission for capability building





Receiver Module

Transmitter on the Ground

Cubes aunch ! (15^{th} Jan. 2017)

(due t

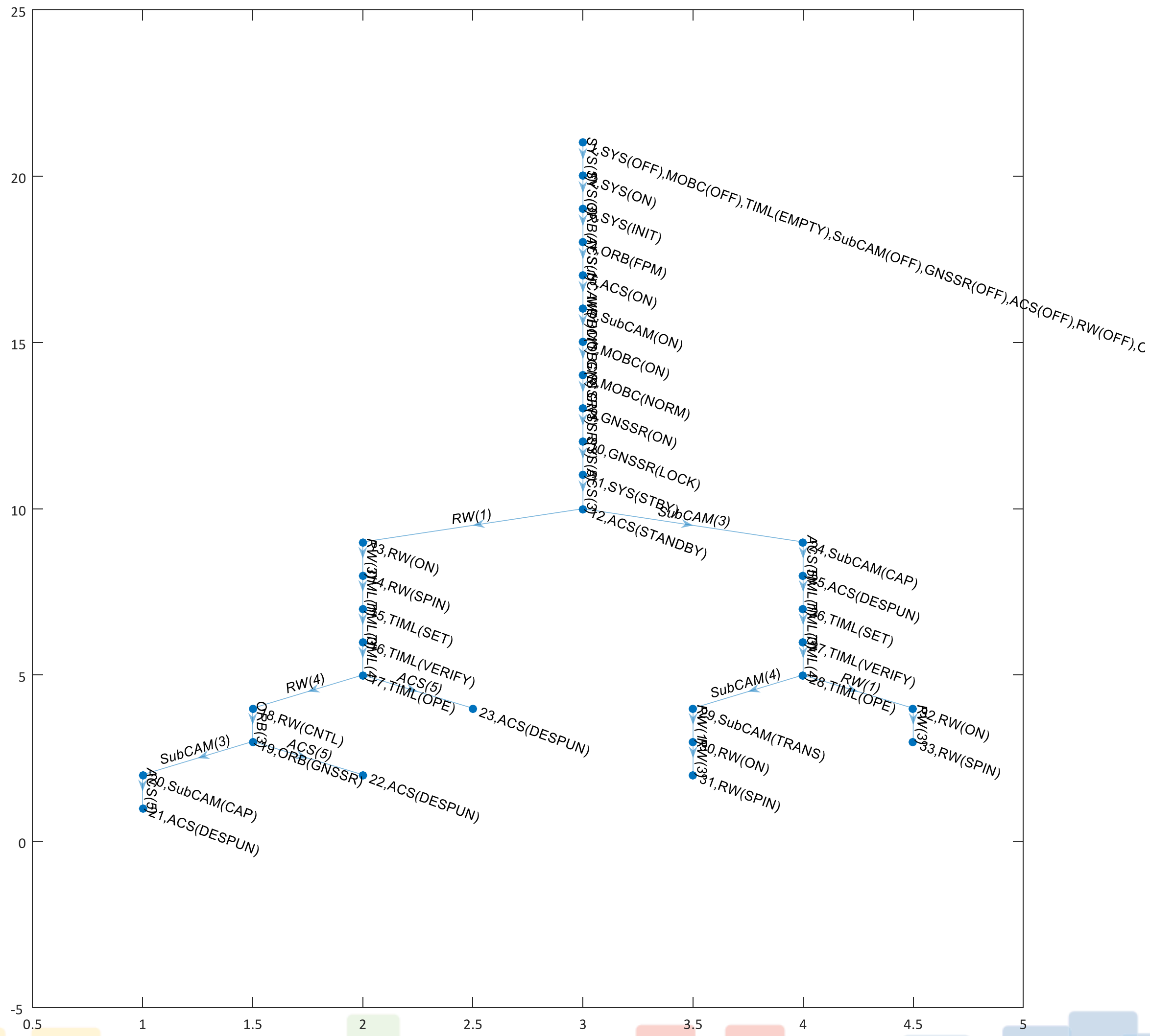
Launc

Good Job! Next Try !
with Autonomy
Demonstration

failure)

Goal Search Result

- Typical 6 passes are generated
- Objective function effectively reduces the numbers of paths to the goal, but leaving enough variety



Objective function

- Objective function is prepared for path search and prioritization of execution

- Execution Cost： number of commands, operation time
- Resilience ： variety of paths
- Resources： battery DoD, data volume
- Modification during mission sequence
  - Objective function parameters is not necessary constant during mission sequence
  - Variations of the path candidate is important during early part of mission scenario
  - Safer path is important after anomaly occurred
  - Relax conditions when operation procedures are not found