Staircase to Utopia: Advances in Technology Roadmapping

2019 MIT Research and Development Conference
13 November 2019

Prof. Olivier de Weck
Senior Vice President for Technology Planning and Roadmapping
Airbus (2017-2018)
deweck@mit.edu
DSN Capability over time

Data Rate [bps]: $10^{-6}$ to $10^{9}$ for $S=750$ Mkm

Timeline: 1960-2020

Flight Missions shown at the bottom

S/C = spacecraft
G = ground
G & S/C = ground + spacecraft change

--- Achieved
- - - - - Projected

Source: JPL
What is a Technology Roadmap?

Example of Technology Roadmap: 2SEA Solar Electric Aircraft

MIT Advanced Technology Roadmap Architecture (ATRA)

16.887/EM.427 New MIT Class
What is a technology roadmap?

“Simple” Technology Roadmap: linking technologies (blue at the bottom) against the products that will implement them (red at the top) along a timeline (x-axis). Source: Bernal et al.

4
What is the purpose of roadmapping?

In a nutshell, the purpose of technology roadmaps in an organization is to:

- **Show the relationships** across technologies, capabilities, products/services, and needs
- **Align investments** in technology and in the new development of new capabilities to deliver on future market needs
- Map technologies to products/missions/services and **define a timeline** for maturation and technology adoption
Different flavors of technology roadmaps

Most basic version of roadmap is to map technologies to products and services. Other flavors are:

- Product planning
- Capability development
- Strategic planning
- Long range planning
- Knowledge planning
- Project planning
- Integration planning
What is your experience with technology roadmapping?

What is your level of experience with technology roadmapping?

I have not seen a technology roadmap yet
I have seen technology roadmaps but not been involved in creating them
I have helped create one or more technology roadmaps
I have led the development of a technology roadmap
I have led the development of an R&D portfolio including roadmapping
I am not sure

http://tiny.cc/TechRM
Sample Roadmap: 2SEA (solar electric aircraft)
Zephyr
Pioneering the stratosphere
1. Roadmap Overview
2. DSM Allocation (interdependencies with others roadmaps)
3. Roadmap Model using OPM (ISO 19450)
4. Figures of Merit (FOM): Definition, name, unit, trends $dFOM/dt$
5. Alignment with Company Strategic Drivers: FOM Targets
6. Positioning of Company vs. Competition: FOM charts
7. Technical Model: Morphological Matrix and Tradespace
8. Financial Model: Technology Value ($\Delta NPV$)
9. List of R&T/R&D Projects and Prototypes
10. Keys Publications, Presentations and Patents
11. Technology Strategy Statement (incl. “arrow” chart)
12. Roadmap Maturity Assessment (optional)
1 Roadmap Overview

Working principle and architecture of a solar-electric aircraft
2 Design Structure Matrix (DSM) Allocation
3 Roadmap Model using Object-Process-Methodology (OPM)
## 4 - Figures of Merit (FOM)

<table>
<thead>
<tr>
<th>FOM name</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Cost</td>
<td>[€]</td>
<td>Unit cost to manufacture the aircraft (incl. amortization of R&amp;D)</td>
</tr>
<tr>
<td>Operating Cost</td>
<td>[€/FH]</td>
<td>Cost per flight-hour, including all variable cost (e.g. energy recharging, battery replacement, and maintenance)</td>
</tr>
<tr>
<td>Maximum Payload</td>
<td>[kg]</td>
<td>Useful payload that can be carried (includes cargo, payload, sensors and comm equipment) and pax</td>
</tr>
<tr>
<td>Endurance</td>
<td>[hrs]</td>
<td>Time-aflot without recharging on the ground</td>
</tr>
<tr>
<td>Energy Storage Density</td>
<td>[kWh/kg]</td>
<td>Energy stored onboard per unit mass of energy storage devices (e.g. batteries)</td>
</tr>
<tr>
<td>Recharging Rate</td>
<td>[kWh/hr]</td>
<td>Rate at which batteries can be recharged on the ground</td>
</tr>
<tr>
<td>Electrical Max Power</td>
<td>[kW]</td>
<td>Total maximum electrical power generated on board by e-machines, for both propulsive and non-propulsive use</td>
</tr>
<tr>
<td>Photovoltaic Cell Efficiency</td>
<td>[%]</td>
<td>Conversion efficiency from incoming photon flux to useable electric current (electron flux)</td>
</tr>
<tr>
<td>Availability</td>
<td>[hrs/y]</td>
<td>Expected number of flight hours the aircraft is available for service per year (excludes maintenance downtime)</td>
</tr>
</tbody>
</table>
## 6 Positioning of Company vs. Competition: FOM charts

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra 330LE</td>
<td>Siemens</td>
<td>2016</td>
<td>1000</td>
<td>100</td>
<td>1</td>
<td>0.33</td>
<td>260</td>
<td>8</td>
</tr>
<tr>
<td>E-Fan 2.0</td>
<td>Airbus</td>
<td>2014</td>
<td>600</td>
<td>200</td>
<td>2</td>
<td>1.45</td>
<td>50</td>
<td>11</td>
</tr>
<tr>
<td>Alpha Electro</td>
<td>Pipistrel</td>
<td>2015</td>
<td>550</td>
<td>200</td>
<td>1</td>
<td>1.42</td>
<td>50</td>
<td>10.5</td>
</tr>
<tr>
<td>Zephyr 7 HAPS</td>
<td>Airbus</td>
<td>2010</td>
<td>53</td>
<td>2.5</td>
<td>0</td>
<td>338.00</td>
<td>0.9</td>
<td>22.5</td>
</tr>
<tr>
<td>Solar Impulse 2</td>
<td>EPFL</td>
<td>2015</td>
<td>2300</td>
<td>100</td>
<td>1</td>
<td>118.00</td>
<td>52</td>
<td>71.9</td>
</tr>
<tr>
<td>SolarEagle</td>
<td>Boeing</td>
<td>defunct</td>
<td>2700</td>
<td>450</td>
<td>0</td>
<td>43800.00</td>
<td>?</td>
<td>130.5</td>
</tr>
<tr>
<td>Solara 50</td>
<td>Titan-Google</td>
<td>defunct</td>
<td>159</td>
<td>32</td>
<td>0</td>
<td>8760.00</td>
<td>7</td>
<td>50</td>
</tr>
</tbody>
</table>
6 Positioning of Company vs. Competition: FOM charts
9 List of R&T (R&D Projects) and Prototypes

Product-specific technical model
(i.e. transfer function)

Product FOMs = \( (y_1, y_2, \ldots, y_m) \)
Technology FOMs = \( (x_1, x_2, \ldots, x_n) \)

\( (y_1, y_2, \ldots, y_m) = f(x_1, x_2, \ldots, x_n) \)

Credit: S. Salgiero (MIT | Aero Astro)
R&T Project Selection for 2SEA

Target requirement: HAPS (i.e. Zephyr) with 10 kg of payload and 500 days of endurance by 2030.

R&T projects available:
1) Li-S battery improvements,
2) Solar cell improvements,
3) Structural improvements

Unable to meet target by 2030 with no projects.
Structural Improvement Project

Unable to meet target by 2030 with Structural Improvements alone.
Solar Cell Improvement Project

Unable to meet target by 2030 with solar cell improvement alone.

No change in aircraft performance with increased solar cell efficiency. Battery capacity is the limiting factor.
Li-S battery improvement project

Able to meet target by 2030 with Li-S battery improvements alone.
2SEA Project Portfolio

1. A **Li-S battery improvement project** with the FOM target of raising the number of charge-discharge cycles from 100 to 500 by 2025. This project will be allocated to the linked 4STO *Energy Storage Roadmap* and executed with a partner who specializes in lithium chemistry-based battery development and certification (with shared IP).

1. A **flight demonstrator project** will be launched as part of the 2SEA roadmap to demonstrate a 10 kg payload and 365 day (one full year) capability by 2027 as a prototype, with an intended EIS of a commercial 500day-10kg-capable product and associated profitable service by 2030.
MIT Advanced Technology Roadmap Architecture (MIT-ATRA)
Step 1: Where are we today?

Dr. Martin Latrille, Airbus
Step 2: Where could we go?

Concurrent Design Facilities
Step 3: Where should we go?
Step 4: Where we are going!

Electrification
- 2MW-class Hybrid-Electric Propulsion
- Fault-Tolerant Electric VTOL

Connectivity
- Software Defined Radio
- Conformal Antenna Arrays

Autonomy
- Adaptive Mission Planning Systems
- Single Pilot Operations

Materials
- Additive 3D Manufacturing with Metals
- Dry-Fiber (Out-of-Autoclave) Composites

Digital Design and Manufacturing (DDM)
- Model-Based Systems Engineering
- Collaborative and Reconfigurable Robotics
How is technology roadmapping used today?

Frequency of application areas for roadmapping (N=81 German companies; multiple responses possible).
Source: Schimpf and Abele (2019)
New MIT Class: 16.887/EM.427  
Technology Roadmapping and Development

- First Offering this semester
- 80 Students enrolled (50 for credit)
- 17 Technology Roadmaps under Development (see below)
- Supported by MIT | Aero Astro and SDM

<table>
<thead>
<tr>
<th>Matter</th>
<th>Energy</th>
<th>Information</th>
<th>Money</th>
<th>Organisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transform</td>
<td>7, Additive Mfg, 17, Hybrid Propulsion</td>
<td>3, Wind Power, 17, Hybrid Propulsion</td>
<td>12, Data Analytics and ML 13, Deep Learning and Computer Detection</td>
<td>9, Plant Genetic Improvement</td>
</tr>
<tr>
<td>Transport</td>
<td>11, Autonomous Driving/Transport</td>
<td></td>
<td>1, Wireless, 16 Optics</td>
<td>11, Autonomous Driving/Transport 15, High-Speed Rail</td>
</tr>
<tr>
<td>Store</td>
<td>2, Cryo Fuels, 4, Inventory Mgmt for Oil and Gas</td>
<td>10, Batteries</td>
<td>4, Inventory Mgmt</td>
<td></td>
</tr>
<tr>
<td>Exchange</td>
<td></td>
<td></td>
<td>5, Wearables</td>
<td>14, E-Commerce and Auctions</td>
</tr>
<tr>
<td>Regulate</td>
<td>6, Ballistic Vest; 8 Autonomous O&amp;G</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions?