Modeling and Analysis of Integration Processes for Engineering Systems

Student 8
Jon Gibbs
16.842
Types of Integration

• Single Stage
  – Small number of subsystems
  – Assumes subsystems acquired simultaneously

• Incremental
  – System too complex for single stage
  – Subsystems can arrive independently
  – Multiple methods
  – Typically have associated time and cost benefits
Large Scale System Development Issues

- Subsystem Development
  - Synchronizing Tasks
- System Development
  - Integration of Subsystems
- System Performance
  - Verification
Relationship Strengths

4 Types of Flow: Information, Energy, Material, Physical

• Degree 0: No significant relationship
• Degree 1: One type of flow only
• Degree 2: Significant flow of two types
• Degree 3: Significant flow of three types

Sharman and Yassine [2004]
Case Study - UAV

- Four UAV subsystems
  1. Engine
  2. Flight control
  3. Optronic payload
  4. Payload control

- How should these systems be integrated?
Single Stage Integration

- Subsystems prepared for integration
- Tightly coupled subsystems integrated separately
- Final systems integration of integrated subsystems
- Total Time: \( \text{Max}(t_1, t_2, t_3, t_4) + d*t_{1,2} + d*t_{3,4} + t_{1,2,3,4} \)

Image by MIT OpenCourseWare. Adapted from Figure 2 on p. 65 in Tahan, Meir, and Joseph Z. Ben-Asher. “Modeling and Analysis of Integration Processes for Engineering Systems.” *Systems Engineering* 8, no. 1 (2005): 62-77.
Incremental Integration

- Subsystems prepared for integration
- First set of tightly coupled subsystems ready for integration triggers integration start
- Assumes that remaining two subsystems ready after first set is integrated
- Integration of all subsystems then performed
- Total Time: Min of \([\text{Max}(t_1,t_2), \text{Max}(t_3,t_4)] + t_{3,4} + d*t_{1,2} + t_{1,2,3,4}\)
## Success Probability

<table>
<thead>
<tr>
<th>Case study</th>
<th>Case 1</th>
<th>Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Single stage</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Incremental</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>


- Incremental integration has higher probability of success
- Single stage integration will perform poorly with complex systems
Types of Incremental Integration

• Option A: Single Stage
  \[ T_s = \text{Max}(t_1, t_2, t_3, t_4) \]

• Option B: Integrate first available units:
  \[ T_s = \text{Min}\{\text{Max}(t_1, t_2), \text{Max}(t_3, t_4)\} \]
  Then integrate other units in order of arrival

Option C: Integration in pairs followed by full system integration

Option D: Integrate the first pair then integrate all available units

Minimize Total Integration Time

Image by MIT OpenCourseWare. Adapted from Figure 4 on p. 66 in Tahan, Meir, and Joseph Z. Ben-Asher, “Modeling and Analysis of Integration Processes for Engineering Systems.” *Systems Engineering* 8, no. 1 (2005): 62-77.
Incremental Options C & D

- Option C
  - (1) Integrate first available
    - Min[Max (t_1, t_2), Max (t_3, t_4)]
  - (2) Integrate in pairs
    - (t_{1,2}, t_{3,4}),
  - (3) Full systems integration
    - (t_{1,2,3,4})
  - \( T_{tot}=\text{Min}[\text{Max} (t_1, t_2), \text{Max} (t_3, t_4)] + t_{3,4} + t_{2,3} + t_{1,2,3,4} \)

- Option D
  - (1) Assume a simulator for unit 1
    - Min[t_2, Max (t_3, t_4)]
  - (2) Integrate remaining pairs with some difficulty
    - d*t_{3,4} or d*t_{1,2}
  - (3) Full systems integration
  - \( T_{tot}=\text{Min}[t_2, (\text{Max} (t_3, t_4) + t_{1,2})] + d*t_{3,4} + t_{2,3} + t_{1,2,3,4} \)
Results

- Difficulty Factor mainly determines break even point
- Replacement time of simulator can be traded with difficulty factor to decide which method has the fastest expected time
- Many firms know the replacement time of a simulator with more certainty than component completion times
Decision Considerations

• Single Vs. Incremental
  – Consider level of complexity

• Simulator:
  – Consider replacement time and level of uncertainty
  – Cost of test equipment and labor

• Type of incremental integration
  – Knowledge of PDF for each method
Very Light Jet Case Study

• Is it faster to prototype or not?

• Approach 1) Obtain FAA approval first, make changes, tackle manufacturing learning curve after

• Approach 2) Prototype first and tackle manufacturing learning curve, obtain FAA approval second, make certification changes last

• Three Variables: $T_{lc}, T_{faa}, d*T_{rework}$
Conclusions

• Incremental integration almost always requires less time than single stage integration

• Incremental integration may be required for complex systems

• Multiple levels of incremental integration exist
Integration Example – Boeing 787/GEnX

- Six Primary Modules
- Fan, LPC, HPC, Combustor, HPT, LPT

Image by MIT OpenCourseWare.
Boeing 787/GEnX Integration

- Aircraft and engines are typically developed in parallel at separate companies and with minimal final integration (relative to aircraft/engine design). What allows this incremental integration to occur?

- Aircraft engine design is typically divided into modules (subsystems). One could argue that the relationship between modules is both tightly and weakly coupled. Why?
Discussion Questions

• Many of the incremental integration models do not assume a particular path, but rather perform sub-system and system integration when the inputs are available. Is there a benefit from planning a target path for integration?

• The paper presents a decent back-to-back study of single stage and incremental integration through various modeling techniques. Is there a benefit for a program to evaluate the integration methodology using these techniques? If so, would the result be quantitative or just qualitative?

• What level of simulator accuracy is required for incremental integration?