Abstract

This module introduces Architectural Reasoning using Conceptual Modeling.
Abstract

The SEMA course System Modeling and Analysis is a 5 day course. Core of the course is Architectural Reasoning Using Conceptual Modeling. This course uses the CAFCR+ model with 6 views. Qualities connect all views. Threads-of-reasoning capture the architectural reasoning across views and qualities. Conceptual models visualize and capture the context, the system and its design. Quantification is a means to make problem and solution space tangible.
# Course Program

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During the SEMA course you work in teams of about 3 persons. Smaller teams (even single persons) are acceptable as well.

Every team preferably works on a real part of a system with some real development that goes on.

We start to model the status quo of the system and then we will model and analyze a change or addition that is being considered.

As preparation for the course I ask you the following:

- Look if the other participants are working on similar systems, such that you can work as team.
- Pick as team a system/component/function/project you will use during the course.
- For this system/component/function/project collect information about: who is the customer, what does the customer need, how is the system used, what technologies are used in the system, what are the main technological challenges et cetera. You do not have to be an expert when you come to the course, but you need to have some feeling for the system you will be working on during the course and presumably also in the 10 week project.
- If you are preparing your master project, then the master project case is probably a good option. This will boost your master project.
Assignments during the Course

1. elevator

2. exploring the case
3. story telling
4. use case
5. dynamic behavior
6. block diagram
7. context and workflow
8. customer key driver graph
9. budget based design
10. concept selection
11. business plan
12. change analysis

13. line of reasoning
14. thread of reasoning
15. quantified chain of models
16. credibility and accuracy
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<td>Dynamic Range of Abstraction Levels in Architecting</td>
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### core

SEMA Method Overview  
http://www.gaudisite.nl/info/SEMAmethodOverviewSlides.pdf  
Short introduction to basic "CAFCR" model  
http://www.gaudisite.nl/info/BasicCAFCR.info.html  
InitialCAFCRscan  
http://www.gaudisite.nl/info/InitialCAFCRscan.info.html

### optional

Architectural Reasoning Explained  
Architectural Reasoning  
http://www.gaudisite.nl/ArchitecturalReasoning.html  
Iteration How To  
http://www.gaudisite.nl/info/IterationHowTo.info.html  
Modeling and Analysis: Iteration and Time-boxing  
http://www.gaudisite.nl/info/MAiterationAndTimeboxing.info.html
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<td>Story Telling in Medical Imaging</td>
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<tr>
<td><a href="http://www.gaudisite.nl/info/MIstories.info.html">http://www.gaudisite.nl/info/MIstories.info.html</a></td>
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### System Partitioning Fundamentals

**Core**

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### Basic Working Methods of a System Architect

**Optional**

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### core

Methods to Explore the Customer Perspective

http://www.gaudisite.nl/info/MethodsToExploreTheCustomerPerspective.info.html

Key Drivers How To

http://www.gaudisite.nl/info/KeyDriversHowTo.info.html

### optional

Medical Imaging Workstation: CAF Views

http://www.gaudisite.nl/info/MIviewsCAF.info.html
### Core

 Modeling and Analysis: Budgeting  
 [http://www.gaudisite.nl/info/MAbudgeting.info.html](http://www.gaudisite.nl/info/MAbudgeting.info.html)

 Concept Selection, Set Based Design and Late Decision Making  
 [http://www.gaudisite.nl/info/ConceptSelectionSetBased.info.html](http://www.gaudisite.nl/info/ConceptSelectionSetBased.info.html)

### Optional

 The Tool Box of the System Architect  
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<td>Modeling and Analysis: Life Cycle Models</td>
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<tr>
<td>How to present architecture issues to higher management</td>
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Qualities as Integrating Needles
http://www.gaudisite.nl/info/QualityNeedles.info.html

Threads of Reasoning
http://www.gaudisite.nl/info/ThreadsOfReasoning.info.html

Threads of reasoning illustrated by medical imaging case
http://www.gaudisite.nl/PresentationMITORSlides.pdf
| core | Modeling and Analysis: Reasoning Approach  |
|      | http://www.gaudisite.nl/info/MAreasoningApproach.info.html |
|      | Modeling and Analysis: Analysis |
|      | http://www.gaudisite.nl/info/MAanalysis.info.html |

| optional | Modeling and Analysis: Measuring  |
|          | http://www.gaudisite.nl/info/MAmeasuring.info.html |
|          | ASP Python Exercise |
|          | http://www.gaudisite.nl/info/ASPpythonExercise.info.html |
## Course Material Wrap-up

### core

Consolidating Architecture Overviews  

SEMA Homework Assignment  
http://www.gaudisite.nl/info/SEMAhomeworkAssigmentSlides.pdf  

### optional

Guidelines for Visualization  
http://www.gaudisite.nl/info/VisualizationGuidelines.info.html  

Granularity of Documentation  
http://www.gaudisite.nl/info/DocumentationGranularity.info.html  

Light Weight Review Process  
http://www.gaudisite.nl/info/LightWeightReview.info.html  

Cookbook A3 Architecture Overview *by Daniel Borches*  
http://www.gaudisite.nl/BorchesCookbookA3architectureOverview.pdf  

How to Create an Architecture Overview  
http://www.gaudisite.nl/info/OverviewHowTo.info.html
Abstract

This presentation explains the basic philosophy behind the SEMA course. The SEMA course in the first place is a course that provides an approach to architectural reasoning. Core to architectural reasoning is the ability to make conceptual models and to use them in conjunction. The course discusses how to make conceptual models, how to get input, and how to use them for analysis. Modeling is put in broader perspective, such as model evolution, simulation, and validation.
You will mostly be working!

One Case during the course and the home work assigment
Work in teams if possible
Select a case close to your day-to-day practice

Learning by Doing
Some theory, apply on case

Case = System of interest + developing organization + some innovative change

Choice of case is critical!
Our Primary Interest

developing organization

architect

system of interest
Context, Zoom-out and Zoom-in

- customer organization
- developing organization
- architect
- supplier organization

- super system
- system of interest
- subsystems
Adding the Time Dimension

过去  现在  未来

顾客组织

开发组织

供应商组织

过去超级系统

系统

未来超级系统

过去系统

子系统

基于TRIZ
Challenges

past  current  future

customer organization  
architect  
organization

heterogeneity  ambiguity

size & complexity  unknowns

system of interest  subsystems

legacy constraints  uncertainties

based on TRIZ

SEMA Basic Philosophy
version: 0.2
March 11, 2015
Gerrit Muller
Theory: typical SE workflow: V-model, requirements management, “top-down”

requirements
specification as input to the design, documented
SMART
Specific, Measurable, Acceptable, Realistic, Traceable

requirements engineering
the flow down of the requirements through the V.

verification
of result against specification

verification
of result against specification

validation

needs

specification

system design

subsystem design

component design

component realization

subsystem test

system test

component test

Practice: Finite knowledge and wisdom causes late disruptions

Innovation and new territory require learning, e.g. experimenting, exploring, failing, discovering complement with “bottom-up”

size & complexity

heterogeneity

ambiguity

unknowns

uncertainties

legacy constraints
**Recommendations as Red Thread**

### principles
- use feedback
- work incremental
- work evolutionary
- be explicit
- make issues tangible

### objectives
- support communication
- facilitate reasoning
- support decision making
- create understanding
- maintain insight
- overview

### recommendations
- Time-box
- Iterate
- Quantify early
- Measure and validate
- Multiple levels of abstraction
- (Simple) mathematical models
- Analysis of accuracy and credibility
- Multi-view
- System and its context
- Visualize

---

**SEMA Basic Philosophy**

version: 0.2
March 11, 2015
MAOrecomendations
Final Delivery: Presentation to Top Management

societal trends opportunities problems needs

business/market trends opportunities problems needs

customers stakeholders key drivers concerns applications

product project system functions key performance

design and concepts functional, physical quantified

specific aspects functional, physical quantified

technology critical or new

summary how solution answers needs

business quantification risk analysis conclusions and recommendations

summary and conclusions why choices are appropriate

SEMA Basic Philosophy
version: 0.2
March 11, 2015
SEMApresentationTshape
Case Selection

Determine the system of interest

Define your organization

Determine an innovative change to be architected

SEMA Basic Philosophy
25 Gerrit Muller
Abstract

An elevator is used as a simple system to model a few physical aspects. We will show simple kinematic models and we will consider energy consumption. These low level models are used to understand (physical) design considerations. Elsewhere we discuss higher level models, such as use cases and throughput, which complement these low level models.
Learning Goals

To understand the need for

- various views, e.g. physical, functional, performance
- mathematical models
- quantified understanding
- assumptions (when input data is unavailable yet) and later validation
- various visualizations, e.g. graphs
- understand and hence model at multiple levels of abstraction
- starting simple and expanding in detail, views, and solutions gradually, based on increased insight

To see the value and the limitations of these conceptual models

To appreciate the complementarity of conceptual models to other forms of modeling, e.g. problem specific models (e.g. structural or thermal analysis), SysML models, or simulations
warning

This presentation starts with a trivial problem.

Have patience!

Extensions to the trivial problem are used to illustrate many different modeling aspects.

Feedback on correctness and validity is appreciated
inhabitants want to reach their destination fast and comfortable

building owner and service operator have economic constraints: space, cost, energy, ...

EPMbuilding
Elementary Kinematic Formulas

\[ S_t = \text{position at time } t \]
\[ v_t = \text{velocity at time } t \]
\[ a_t = \text{acceleration at time } t \]
\[ j_t = \text{jerk at time } t \]

\[
\begin{align*}
    v &= \frac{dS}{dt} \\
a &= \frac{dv}{dt} \\
j &= \frac{da}{dt}
\end{align*}
\]

Position in case of uniform acceleration:

\[ S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2 \]
Initial Expectations

What values do you expect or prefer for these quantities? Why?

\[ t_{\text{top floor}} = \text{time to reach top floor} \]
\[ v_{\text{max}} = \text{maximum velocity} \]
\[ a_{\text{max}} = \text{maximum acceleration} \]
\[ j_{\text{max}} = \text{maximum jerk} \]
Initial Estimates via Googling

Google "elevator" and "jerk":

- \( t_{\text{top floor}} \approx 16 \text{ s} \)
- \( v_{\text{max}} \approx 2.5 \text{ m/s} \)
- \( a_{\text{max}} \approx 1.2 \text{ m/s}^2 \) (up)
- \( j_{\text{max}} \approx 2.5 \text{ m/s}^3 \)

- 12% of gravity; weight goes up
- relates to motor design and energy consumption
- relates to control design
- humans feel changes of forces
- high jerk values are uncomfortable

numbers from: http://www.sensor123.com/vm_eva625.htm
CEP Instruments Pte Ltd Singapore
Exercise Time to Reach Top Floor Kinematic

**input data**

<table>
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<tr>
<th>S_0</th>
<th>S_t</th>
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<tbody>
<tr>
<td>0 m</td>
<td>40 m</td>
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</tbody>
</table>

v_{\text{max}} = 2.5 \text{ m/s}

a_{\text{max}} = 1.2 \text{ m/s}^2 \text{ (up)}

j_{\text{max}} = 2.5 \text{ m/s}^3

**elementary formulas**

\[
v = \frac{dS}{dt}, \quad a = \frac{dv}{dt}, \quad j = \frac{da}{dt}
\]

Position in case of uniform acceleration:

\[
S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2
\]

**exercises**

\( t_{\text{top floor}} \) is time needed to reach top floor without stopping

Make a model for \( t_{\text{top floor}} \) and calculate its value

Make 0\textsuperscript{e} order model, based on constant velocity

Make 1\textsuperscript{e} order model, based on constant acceleration

What do you conclude from these models?
Models for Time to Reach Top Floor

**Input Data**
- $S_0 = 0\text{m}$
- $S_{\text{top floor}} = 40\text{m}$
- $v_{\text{max}} = 2.5\text{ m/s}$
- $a_{\text{max}} = 1.2\text{ m/s}^2$ (up)
- $j_{\text{max}} = 2.5\text{ m/s}^3$

**Elementary Formulas**

\[
\begin{align*}
    v &= \frac{dS}{dt} \\
    a &= \frac{dv}{dt} \\
    j &= \frac{da}{dt}
\end{align*}
\]

Position in case of uniform acceleration:
\[
S_t = S_0 + v_0 t + \frac{1}{2} a_{\text{max}} t^2
\]

**0th Order Model**
- $S_{\text{top floor}} = v_{\text{max}} \cdot t_{\text{top floor}}$
- $t_{\text{top floor}} = S_{\text{top floor}} / v_{\text{max}}$
- $t_{\text{top floor}} = 40/2.5 = 16\text{ s}$

**1st Order Model**
- $t_a \approx 2.5/1.2 \approx 2\text{ s}$
- $S(t_a) \approx 0.5 \times 1.2 \times 2^2$
- $S(t_a) \approx 2.4\text{ m}$
- $t_v \approx (40-2\times2.4)/2.5$
- $t_v \approx 14\text{ s}$
- $t_{\text{top floor}} \approx 2 + 14 + 2$
- $t_{\text{top floor}} \approx 18\text{ s}$
Conclusions

$v_{\text{max}}$ dominates traveling time

The model for the large height traveling time can be simplified into:

$$t_{\text{travel}} = \frac{S_{\text{travel}}}{v_{\text{max}}} + (t_a + t_j)$$
Exercise Time to Travel One Floor

**input data**

- \( S_0 = 0 \text{m} \)
- \( S_{\text{top floor}} = 40 \text{m} \)
- \( v_{\text{max}} = 2.5 \text{ m/s} \)
- \( a_{\text{max}} = 1.2 \text{ m/s}^2 \) (up)
- \( j_{\text{max}} = 2.5 \text{ m/s}^3 \)

**elementary formulas**

\[
\begin{align*}
  v &= \frac{dS}{dt} \\
  a &= \frac{dv}{dt} \\
  j &= \frac{da}{dt}
\end{align*}
\]

Position in case of uniform acceleration:

\[
S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2
\]

**exercise**

Make a model for \( t_{\text{one floor}} \) and calculate it.

What do you conclude from this model?
2nd Order Model Moving One Floor

**Input Data**
- \( S_0 = 0 \text{ m} \)
- \( S_{\text{one floor}} = 3 \text{ m} \)
- \( v_{\text{max}} = 2.5 \text{ m/s} \)
- \( a_{\text{max}} = 1.2 \text{ m/s}^2 \) (up)
- \( j_{\text{max}} = 2.5 \text{ m/s}^3 \)

**Equations**

- \( t_{\text{one floor}} = 2 \ t_a + 4 \ t_j \)
- \( t_j = \frac{a_{\text{max}}}{j_{\text{max}}} \)
- \( S_1 = \frac{1}{6} \ j_{\text{max}} t_j^3 \)
- \( v_1 = 0.5 \ j_{\text{max}} t_j^2 \)
- \( S_2 = S_1 + v_1 t_a + 0.5 \ a_{\text{max}} t_a^2 \)
- \( v_2 = v_1 + a_{\text{max}} t_a \)
- \( S_3 = S_2 + v_2 t_j + 0.5 \ a_{\text{max}} t_j^2 - \frac{1}{6} j_{\text{max}} t_j^3 \)

**Results**
- \( t_j \sim = 1.2/2.5 \sim = 0.5 \text{ s} \)
- \( S_1 \sim = \frac{1}{6} * 2.5 * 0.5^3 \sim = 0.05 \text{ m} \)
- \( v_1 \sim = 0.5 * 2.5 * 0.5^2 \sim = 0.3 \text{ m/s} \)

**Et cetera**

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Physical Models of an Elevator
37  Gerrit Muller
1st Order Model Moving One Floor

**1st order model**

- **Input data**
  - $S_{\text{one floor}} = 3\text{ m}$
  - $v_{\text{max}} = 2.5 \text{ m/s}$
  - $a_{\text{max}} = 1.2 \text{ m/s}^2$ (up)
  - $j_{\text{max}} = 2.5 \text{ m/s}^3$

- **Solution**
  - $S(t_a) = \frac{1}{2} \cdot a_{\text{max}} \cdot t_a^2$
  - $t_a = \sqrt{\frac{S(t_a)}{0.5 \cdot a_{\text{max}}}}$
  - $t_{\text{one floor}} = 2 \cdot t_a = 2 \sqrt{\frac{S(t_a)}{0.5 \cdot a_{\text{max}}}}$
  - $v(t_a) = a_m t_a \quad v(t_a) \approx 1.2 \cdot 1.6 \approx 1.9 \text{ m/s}$

**Coarse 2nd order correction**

- $t_{\text{one floor}} = 2 \cdot t_a + 2 \cdot t_j$
  - $t_j \approx 0.5\text{ s}$
  - $t_{\text{one floor}} \approx 2 \cdot 1.6 + 2 \cdot 0.5 \approx 4\text{ s}$
Conclusions

\( a_{\text{max}} \) dominates travel time

The model for small height traveling time can be simplified into:

\[
 t_{\text{travel}} = 2 \sqrt{\frac{S_{\text{travel}}}{0.5 \ a_{\text{max}}}} + t_j
\]
exercise

Make a model for $t_{\text{top floor}}$
Take door opening and docking into account
What do you conclude from this model?
Elevator Performance Model

**functional model**
- close doors
- undock elevator
- move elevator
- dock elevator
- open doors elevator

**performance model**
\[
t_{\text{top floor}} = t_{\text{close}} + t_{\text{undock}} + t_{\text{move}} + t_{\text{dock}} + t_{\text{open}}
\]

**assumptions**
- \( t_{\text{close}} \sim t_{\text{open}} \sim 2\text{s} \)
- \( t_{\text{undock}} \sim 1\text{s} \)
- \( t_{\text{dock}} \sim 2\text{s} \)
- \( t_{\text{move}} \sim 18\text{s} \)

**outcome**
- \( t_{\text{top floor}} \sim 2 + 1 + 18 + 2 + 2 \)
- \( t_{\text{top floor}} \sim 25\text{s} \)
Conclusions

The time to move is dominating the traveling time.

Docking and door handling is significant part of the traveling time.

\[ t_{\text{top floor}} = t_{\text{travel}} + t_{\text{elevator overhead}} \]
Measured Elevator Acceleration

![Graph of measured elevator acceleration](http://www.sensor123.com/vm_eva625.htm)

CEP Instruments Pte Ltd Singapore
What did we ignore or forget?

acceleration: up <> down 1.2 m/s² vs 1.0 m/s²

slack, elasticity, damping et cetera of cables, motors....

ccontroller impact
exercise

Make a model for \( t_{\text{one floor}} \)
Take door opening and docking into account
What do you conclude from this model?
### Elevator Performance Model

#### functional model

- close doors
- undock elevator
- move elevator
- dock elevator
- open doors elevator

#### performance model one floor (3m)

\[
t_{\text{one floor}} = t_{\text{close}} + t_{\text{undock}} + t_{\text{move}} + t_{\text{dock}} + t_{\text{open}}
\]

#### assumptions

- \( t_{\text{close}} \sim= t_{\text{open}} \sim= 2\text{s} \)
- \( t_{\text{undock}} \sim= 1\text{s} \)
- \( t_{\text{dock}} \sim= 2\text{s} \)
- \( t_{\text{move}} \sim= 4\text{s} \)

#### outcome

\[
t_{\text{one floor}} \sim= 2 + 1 + 4 + 2 + 2 = 11\text{s}
\]
Conclusions

Overhead of docking and opening and closing doors is dominating traveling time.

Fast docking and fast door handling has significant impact on traveling time.

\[ t_{\text{one floor}} = t_{\text{travel}} + t_{\text{elevator overhead}} \]
Exercise
Make a time line of people using the elevator. Estimate the time needed to travel to the top floor. Estimate the time needed to travel one floor. What do you conclude?
Time Line; Humans Using the Elevator

**assumptions human dependent data**

\[ t_{\text{wait for elevator}} = [0\ldots 2 \text{ minutes}] \text{ depends heavily on use} \]

\[ t_{\text{wait for leaving people}} = [0\ldots 20 \text{ seconds}] \text{ idem} \]

\[ t_{\text{walk in}} \approx t_{\text{walk out}} \approx 2 \text{ s} \]

\[ t_{\text{select floor}} \approx 2 \text{ s} \]

**assumptions additional elevator data**

\[ t_{\text{minimal waiting time}} \approx 8 \text{ s} \]

\[ t_{\text{travel top floor}} \approx 25 \text{ s} \]

\[ t_{\text{travel one floor}} \approx 11 \text{ s} \]

**outcome**

\[ t_{\text{one floor}} = t_{\text{minimal waiting time}} + t_{\text{walk out}} + t_{\text{travel one floor}} + t_{\text{wait}} \]

\[ t_{\text{top floor}} = t_{\text{minimal waiting time}} + t_{\text{walk out}} + t_{\text{travel top floor}} + t_{\text{wait}} \]

\[ t_{\text{one floor}} \approx 8 + 2 + 11 + t_{\text{wait}} \]

\[ \approx 21 \text{ s} + t_{\text{wait}} \]

\[ t_{\text{top floor}} \approx 8 + 2 + 25 + t_{\text{wait}} \]

\[ \approx 35 \text{ s} + t_{\text{wait}} \]
Overview of Results for One Elevator

**Top Floor**

- **0\textsuperscript{th} order time to move elevator 40m**: 16s
- **1\textsuperscript{st} order correction elevator docking and doors**: 2s
- **Human related waiting time**: 7s
- **Total waiting time**: $35s + t_{\text{wait}}$

**One Floor**

- **0\textsuperscript{th} order time to move elevator 40m**: 16s
- **1\textsuperscript{st} order model**: 3s
- **1\textsuperscript{st} order correction**: 1s
- **Human related waiting time**: 10s
- **Total waiting time**: $21s + t_{\text{wait}}$
Conclusions

The human related activities have significant impact on the end-to-end time.

The waiting times have significant impact on the end-to-end time and may vary quite a lot.

\[ t_{\text{end-to-end}} = t_{\text{human activities}} + t_{\text{wait}} + t_{\text{elevator travel}} \]
Exercise

Estimate the energy consumption and the average and peak power needed to travel to the top floor.

What do you conclude?
Energy and Power Model

**Input Data**
- \( S_0 = 0 \text{m} \)
- \( S_t = 40 \text{m} \)
- \( v_{\text{max}} = 2.5 \text{ m/s} \)
- \( m_{\text{elevator}} = 1000 \text{ Kg} \) (incl counter weight)
- \( a_{\text{max}} = 1.2 \text{ m/s}^2 \) (up)
- \( j_{\text{max}} = 2.5 \text{ m/s}^3 \)
- \( g = 10 \text{ m/s}^2 \)

**Elementary Formulas**
- \( E_{\text{kin}} = \frac{1}{2}mv^2 \)
- \( E_{\text{pot}} = mgh \)
- \( W = \frac{\text{d}E}{\text{dt}} \)

\[ E_{\text{kin max}} = \frac{1}{2}m v_{\text{max}}^2 \]
\[ \approx 0.5 \times 1100 \times 2.5^2 \]
\[ \approx 3.4 \text{ kJ} \]

\[ W_{\text{kin max}} = m v_{\text{max}} a_{\text{max}} \]
\[ \approx 1100 \times 2.5 \times 1.2 \]
\[ \approx 3.3 \text{ kW} \]

\[ E_{\text{pot}} = mgh \]
\[ \approx 100 \times 10 \times 40 \]
\[ \approx 40 \text{ kJ} \]

\[ W_{\text{pot max}} \approx E_{\text{pot}}/t_v \]
\[ \approx 40/16 \]
\[ \approx 2.5 \text{ kW} \]

**1st Order Model**

**Ignored:**
- friction and other losses
- efficiency of energy transfer
Conclusions

$E_{\text{pot}}$ dominates energy balance

$W_{\text{pot}}$ is dominated by $v_{\text{max}}$

$W_{\text{kin}}$ causes peaks in power consumption and absorption

$W_{\text{kin}}$ is dominated by $v_{\text{max}}$ and $a_{\text{max}}$

\[
E_{\text{kin max}} = \frac{1}{2} m v_{\text{max}}^2 \\
\approx 0.5 \times 1100 \times 2.5^2 \\
\approx 3.4 \text{ kJ}
\]

\[
W_{\text{kin max}} = m v_{\text{max}} a_{\text{max}} \\
\approx 1100 \times 2.5 \times 1.2 \\
\approx 3.3 \text{ kW}
\]

\[
E_{\text{pot}} = mgh \\
\approx 100 \times 10 \times 40 \\
\approx 40 \text{ kJ}
\]

\[
W_{\text{pot max}} \approx E_{\text{pot}}/v \\
\approx 40/16 \\
\approx 2.5 \text{ kW}
\]
Exercise

What other qualities and design considerations relate to the kinematic models?
Examples of other qualities and design considerations

- **Safety**
  - $v_{\text{max}}$

- **Acoustic noise**
  - $v_{\text{max}}, a_{\text{max}}, j_{\text{max}}$

- **Mechanical vibrations**
  - $v_{\text{max}}, a_{\text{max}}, j_{\text{max}}$

- **Air flow**
  - $\text{?}$

- **Operating life, maintenance**
  - Duty cycle, $\text{?}$

- **Obstacles cause vibrations**

Physical Models of an Elevator

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Other Domains

applicability in other domains

kinematic modeling can be applied in a wide range of domains:
transportation systems (trains, busses, cars, containers, ...)
waffer steapper stages
health care equipment patient handling
material handling (printers, inserters, ...)
MRI scanners gradient generation
...

Physical Models of an Elevator
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EPMotherDomains
Exercise

Assume that a group of people enters the elevator at the ground floor. On every floor one person leaves the elevator.

What is the end-to-end time for someone traveling to the top floor?

What is the desired end-to-end time?

What are potential solutions to achieve this?

What are the main parameters of the design space?
Multiple Users Model

\[ \text{outcome} \approx 13 \times (8 + 11) + 2 + t_{\text{wait}} \]

**elevator data**
- \( t_{\text{min wait}} \approx 8 \text{s} \)
- \( t_{\text{one floor}} \approx 11 \text{s} \)
- \( t_{\text{walk out}} \approx 2 \text{s} \)
- \( n_{\text{floors}} = 40 \div 3 + 1 = 14 \)
- \( n_{\text{stops}} = n_{\text{floors}} - 1 = 13 \)

**outcome**
- \( t_{\text{end-to-end}} = n_{\text{stops}} \left( t_{\text{min wait}} + t_{\text{one floor}} \right) + t_{\text{walk out}} + t_{\text{wait}} \)
  \[ \approx 13 \times (8 + 11) + 2 + t_{\text{wait}} \]
  \[ \approx 249 \text{s} + t_{\text{wait}} \]

- \( t_{\text{non-stop}} \approx 35 \text{s} + t_{\text{wait}} \)
Considerations

desired time to travel to top floor \(<\, 1\) minute

note that \(t_{\text{wait next}} = t_{\text{travel up}} + t_{\text{travel down}}\)

if someone just misses the elevator then the waiting time is

\[
t_{\text{end-to-end}} \approx 249 + 35 + 249 = 533s \approx 9\, \text{minutes!}
\]

desired waiting time \(<\, 1\) minute
Design of a system with multiple elevator requires a different kind of models: oriented towards logistics.
Exceptional Cases

- non-functioning elevator
- maintenance, cleaning of elevator
- elevator used by people moving household
- rush hour
- special events (e.g. party, new years eve)
- special floors (e.g. restaurant)
- many elderly or handicapped people
- playing children
Make a list of all *visualizations* and *representations* that we used during the exercises.
Summary of Visualizations and Representations

**Mathematical Formulas**

\[ S_t = S_0 + v_0 t + \frac{1}{2} a_0 t^2 \]

\[ t_{\text{top floor}} = t_{\text{close}} + t_{\text{undock}} + t_{\text{move}} + t_{\text{dock}} + t_{\text{open}} \]

**Physical Models of an Elevator**

- Functional Model
  - Close doors
  - Undock elevator
  - Move elevator
  - Dock elevator
  - Open doors elevator

**Functional Model Diagram**

- Press button
- Wait for elevator
- Walk in
- Select floor
- Minimal waiting time
- Other people entering
- Wait for leaving people
- Dock elevator
- Open doors
- Travel
- Walk out

**Timeline, Concurrency**

**Measurement Graph**

**Graph Reproduced From:**

http://www.sensor123.com/vm_eva625.htm

CEP Instruments Pte Ltd Singapore

**Quantification**

\[ t_{\text{top floor}} \approx 25s \]

\[ t_{\text{top floor}} \approx 21s + t_{\text{wait}} \]

- Waiting time
  - 21s
- Human related
  - 10s
- Elevator docking and doors
  - 11s
- 1st order model
  - 3+1s
- 2nd order correction
  - 4s
Architecting Scope and Challenges

Scope

- *past system of interest*
- *current system of interest*
- *future system of interest*
- *past super system*
- *future super system*
- *past customer organization super system*
- *future customer organization super system*
- *past subsystems*
- *future subsystems*
- Based on TRIZ

Challenges

- *past system of interest*
- *current system of interest*
- *future system of interest*
- *past super system*
- *future super system*
- *past subsystems*
- *future subsystems*
- Based on TRIZ

Recommendations

- **principles**
  - use feedback
  - work incremental
  - work evolutionary
  - be explicit
  - make issues tangible

- **objectives**
  - support communication
  - facilitate reasoning
  - support decision making
  - create maintain understanding insight overview

- **recommendations**
  - Time-box
  - Iterate
  - Quantify early
  - Measure and validate
  - Multiple levels of abstraction
  - (Simple) mathematical models
  - Analysis of accuracy and credibility
  - Multi-view
  - System and its context
  - Visualize

Final Top-Down Delivery

- Societal trends
- Business market competition
- Design and concepts functional, physical quantified
- Summary how solution answers needs

- Technology critical or new
- Product project system functions key performance
- Specific aspects functional, physical quantified
- Conclusions and recommendations

Summary Module Architectural Reasoning Introduction

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Introduction Conceptual Modeling

Zooming Out

**top floor**
- $t_{wait}$: waiting time
- $35s + t_{wait}$
- $10s$: human related
- $25s$: elevator docking and doors
- $7s$: $t_{wait}$
- $16s$: $0^{th}$ order time to move elevator 40m

**one floor**
- $21s + t_{wait}$
- $16s$: $t_{wait}$
- $21s$: human related
- $4s$: elevator docking and doors
- $3 + 1s$: $1^{st}$ order correction

Complementary Visualizations and Representations

Mathematical formulas
- Schematic graphs
- Measurement graph
- Quantification
- Timeline, concurrency

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