State University of Campinas (UNICAMP)
Campinas, SP – Brasil

Lifetime Maximization With Multiple Battery Levels in Irregularly Distributed Wireless Sensor Networks

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- Introduction
- Analysis
- Validation
- Experiments
- Conclusions

Introduction

- **Wireless Sensor Networks**
  - **Wide Use**
    - **Civilian Applications**
      - **Meteorology, Surveillance, Environmental Studies**
    - **Military Applications**
      - **Surveillance, Battlefield Vigilance**

Introduction

- **Wireless Sensor Networks**
  - **Cooperative operation of many *motes*.**

Introduction

- **Wireless Sensor Networks**
  - **Fast evolution of electronics devices was not followed by batteries and other energy sources.**
    - **Computational Problems: Temporary** C
      - **Processors, Memory, Sensors etc.**
    - **Energy Problems: Constant** D
      - **Low-capacity Batteries, short network *lifetime* etc.**

Irregular Energy Consumption

- ***Energy Hole / Doughnut Effect***
  - ***Circular Networks***
  - **Nodes close to Base Station die faster than others.**

Problem

- **High Energy Waste**
  - **More than 90%**
- **Network lifetime was very short even with large energy budgets**

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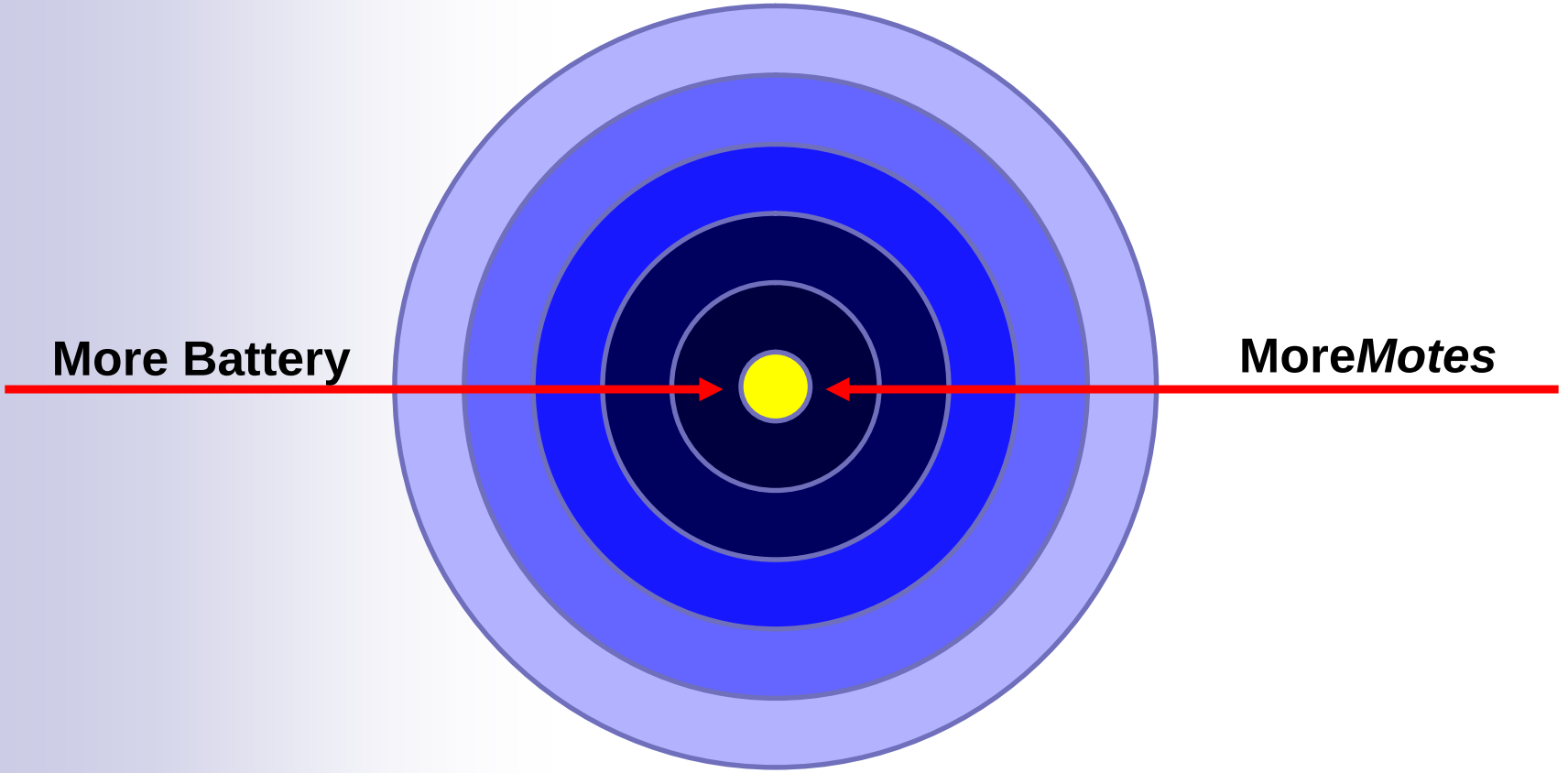
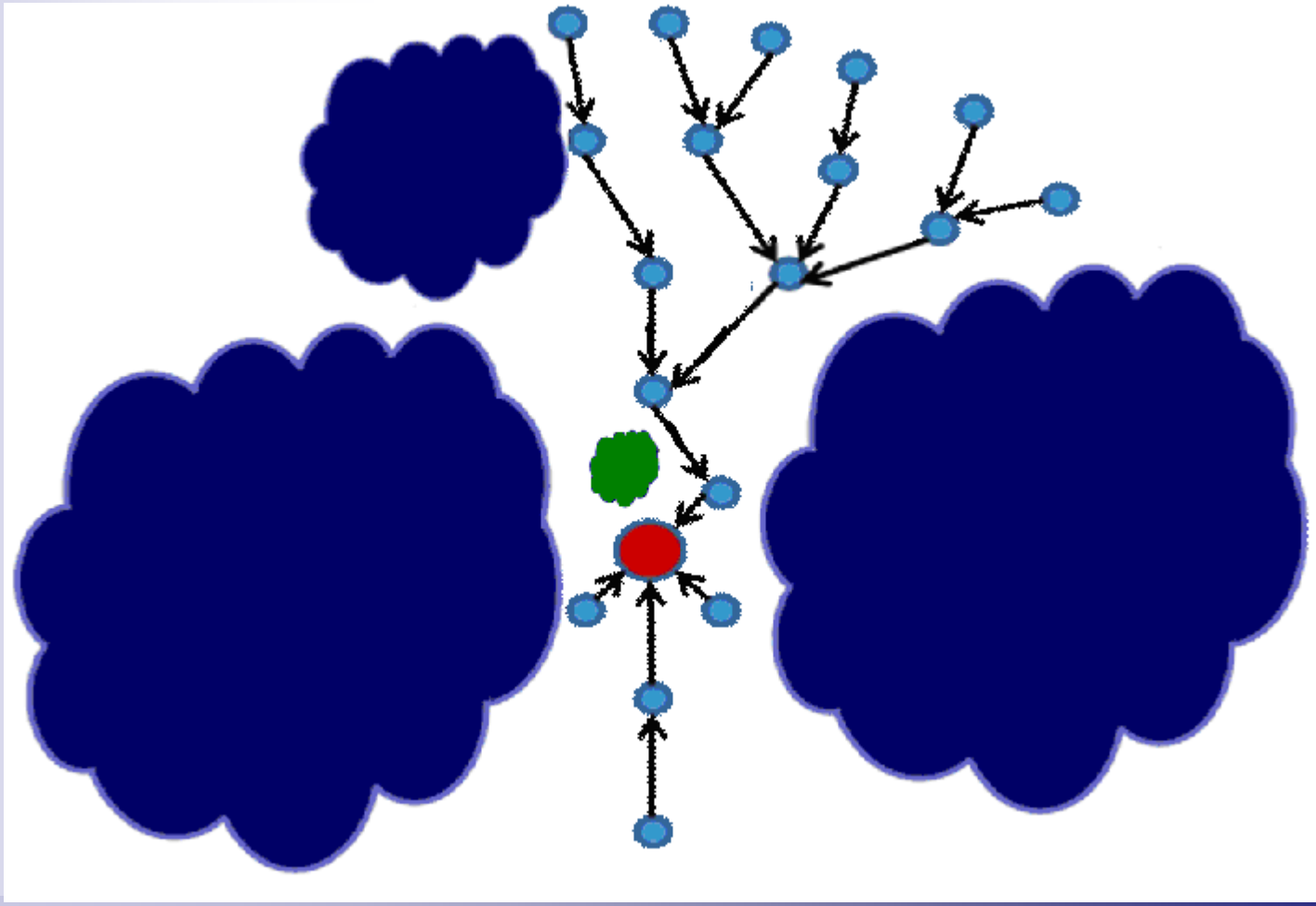
Wireless Sensor Networks Inherent Problems

Available Strategies



Real Networks

Obstacles forbids a perfect physical organization



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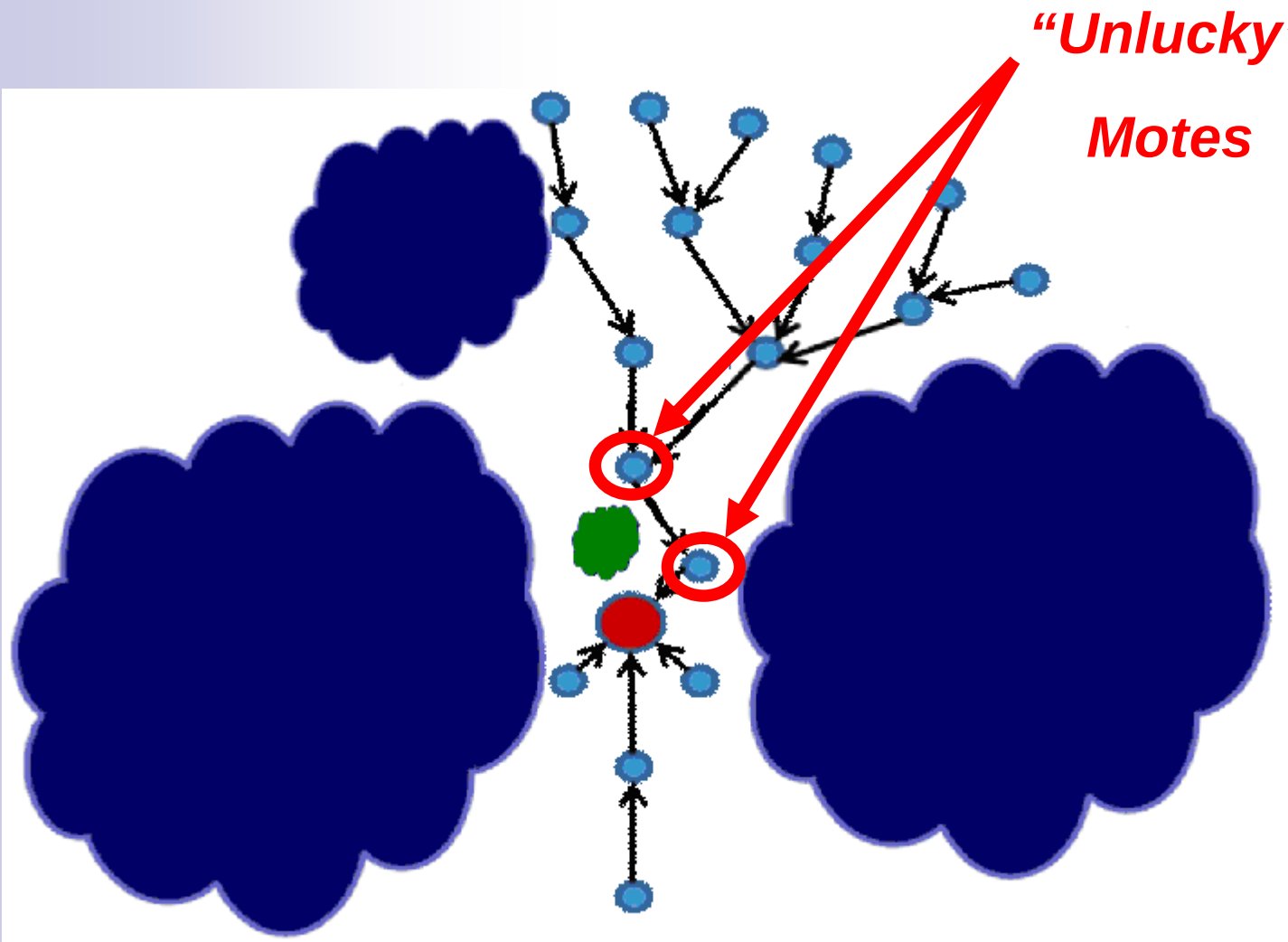


Proposal

- **Estimate each the consumption of each mote**
  - **Assign different batteries according to how much energy a mote needs**
  - **Reduce energy waste**
  - **Increase *Network Lifetime***

Estimating Energy Consumption on Irregularly Distributed WSN

- **Based on *Time-Driven* Networks**
  - ***Defined Network Cycles***
  - ***Repetitive Tasks***
  - ***Predictive Actions***

Estimating Energy Consumption on Irregularly Distributed WSN

- **Inclusion of many energy related actions on the energy consumption model**
  - ***Sent Messages***
  - ***Received Messages***
    - ***Overheard messages***
  - ***Other tasks***
    - ***Sensors Reading, Message Rerouting etc.***

Estimating Energy Consumption on Irregularly Distributed WSN

$$Ql_{msg_x} = Porl_x \times f_m$$

Ql_{msg} Quantity of generated-message flows sent through a link.

$Porl$ Portion of message flows that will be routed through a link.

f Generation frequency of new messages.

Estimating Energy Consumption on Irregularly Distributed WSN

$$Ql_{Rrmsg_x} = Por l_x \times F_{Rx_m}$$

Ql_{Rrmsg} Quantity of rerouted-message flows forwarded through a link.

$Por l$ Portion of message flows that will be routed through a link.

F_{Rx} Quantity of received message flows.

Estimating Energy Consumption on Irregularly Distributed WSN

$$B_{abs_m} = M_{Rr_m} + f_m$$

B_{abs} Absolute burden of a mote.

M_{Rr} Number of messages **rerouted** by a mote.

f Generation frequency of new messages.

Estimating Energy Consumption on Irregularly Distributed WSN

$$M_{Rx_m} = \sum_{i=1}^{w} B_{abs_i} \quad \text{, where} \quad B_{abs_m} = 0 \; \forall \; i \notin N_m$$

M_{Rx} Number of messages **received** by a mote.

B_{abs} Absolute burden of a mote.

N_m Set containing all neighbors of mote *m*.

Mapa de Fluxos de Mensagens

$$Ec_m = f_m(E_{sens\,m}) + B_{abs\,m}(E_{Tx\,m}) + M_{Rx\,m}(E_{Rx\,m})$$

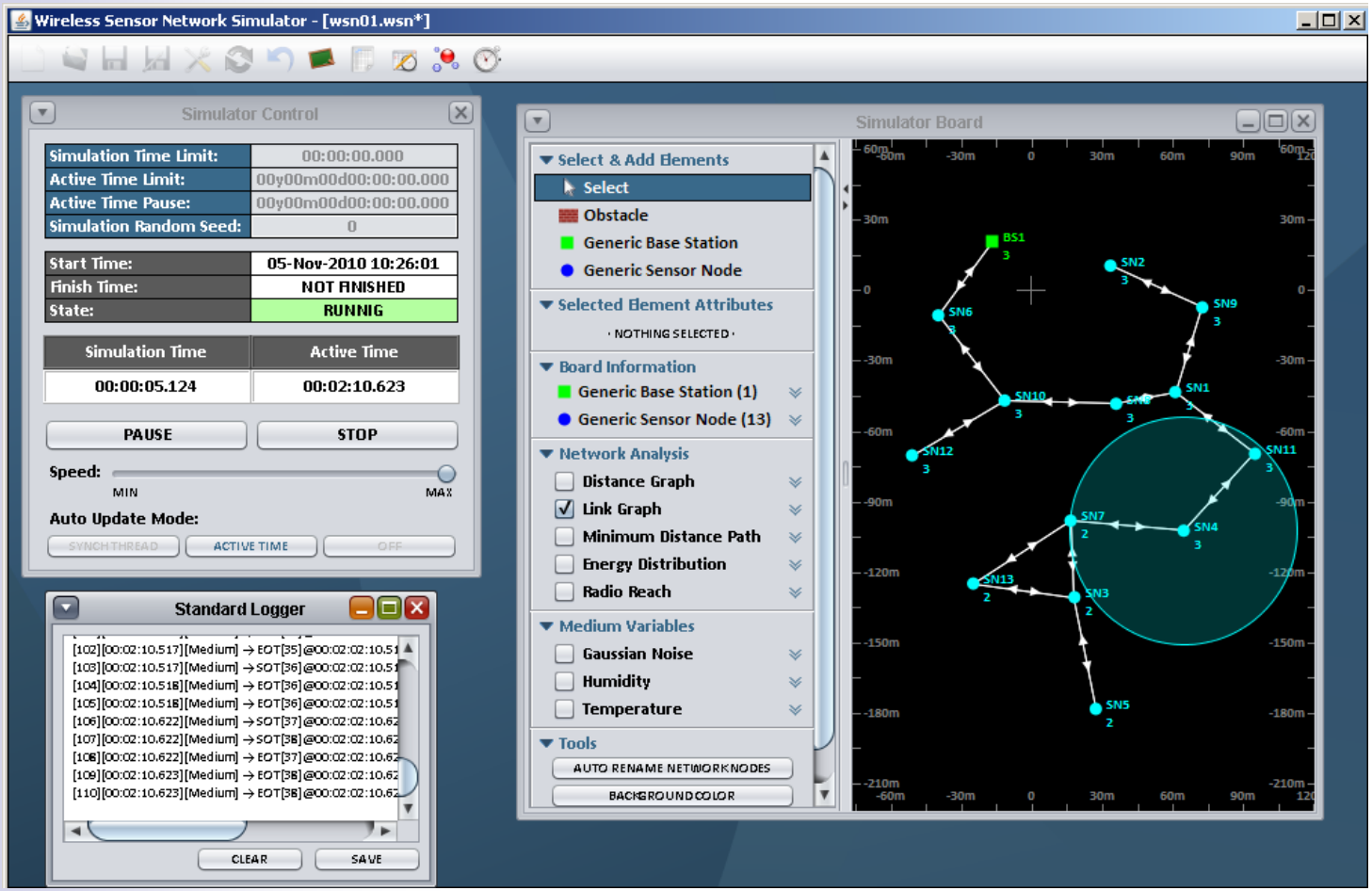
Ec	Energy consumption of a mote.
E_{sens}	Energy required to a mote read all its sensors.
E_{Tx}	Energy required to transmit a message.
E_{Rx}	Energy required to receive a message.

Energy Assign

- **Planned Energy Assignment**
  - ***Each mote/sector can receive an appropriated energy amount***
  - ***Energy consumption of each mote is know***
    - ***Network lifetime increment***
    - ***Less energy waste***

Validation

- **Simulations**

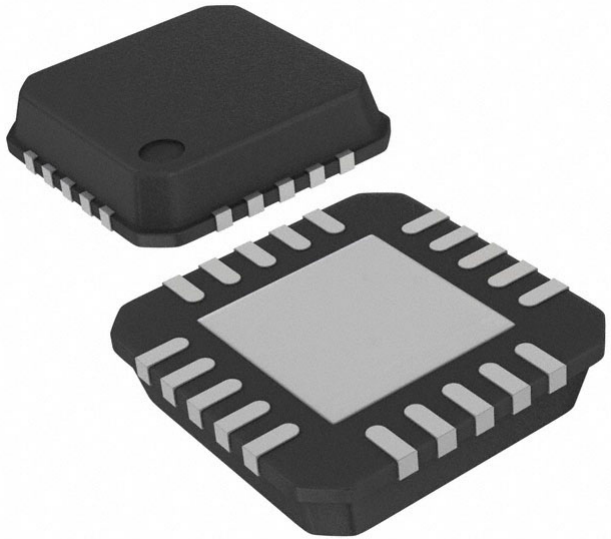


Validation

- **Some models of well-accepted commercial devices**
  - **Radio Transceiver**
    - **CC2500 (Texas Instruments)**
  - **Microcontroller**
    - **ATMEGA8 (Atmel)**
  - **Sensor**
    - **SHT11 (Sensirion)**
  - **Antenna**
    - **W1030 (Pulse)**
  - **Battery**
    - **Phillips models**

Validation

- **CC2500 (Texas Instruments)**
  - **Clear Channel Assessment (CCA)**
    - **Used on CSMA/CA and IEEE 802.11**



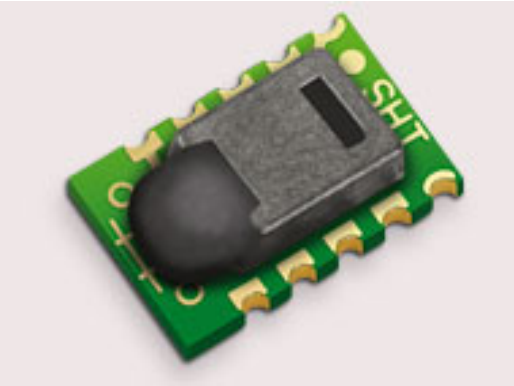
Validation

- **Atmega8 (Atmel)**

Atmega8			
SPI	ADC	Timers	Sleep
Yes	Yes	Yes	7 States

Validation

- **SHT11 (Sensirion)**



  - **Temperature and Humidity**
  - **3V**
  - **Digital Output**

Validation

- **Antenna (Pulse)**
  - **Omnidirectional**
  - **2,4 – 2,5 GHz**

Validation

- **Batteries**
  - **Coin Model**
  - **Phillips**

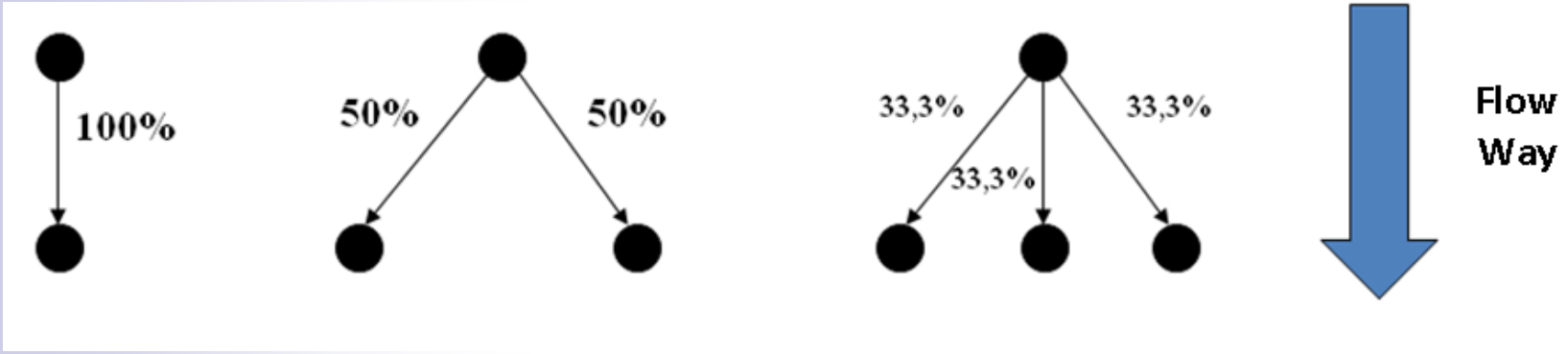
Experiments

Experiments

- **Three Different Networks**
  - **Normal Distribution (same energy) x Energy Reallocation**
    - **Same energy budget**
  - **Base Station Displacement**
    - **Irregular distribution scenarios**
  - **Simulations using pure CSMA/CA**
  - **Simulations using IEEE 802.11 RTS/CTS**

Experiments

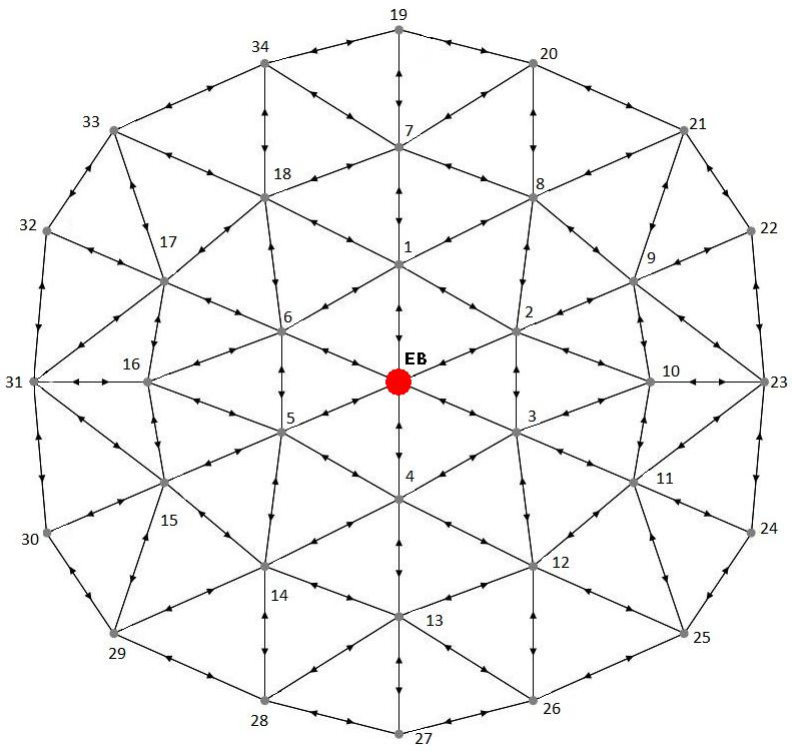
- **Sending and Rerouting Policy:**



Simulations using pure CSMA/CA

Validation

- **Base Station put in the middle**
  - **Perfect organized scenario**



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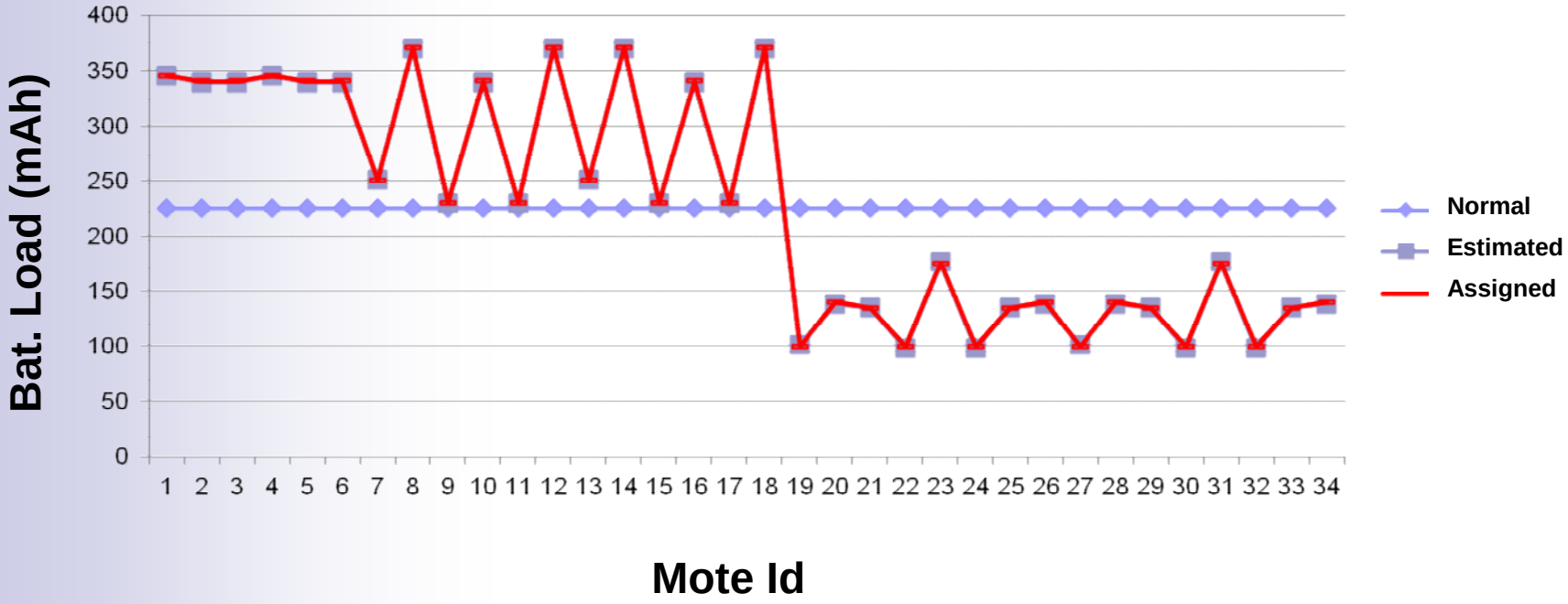
Energy Assignment



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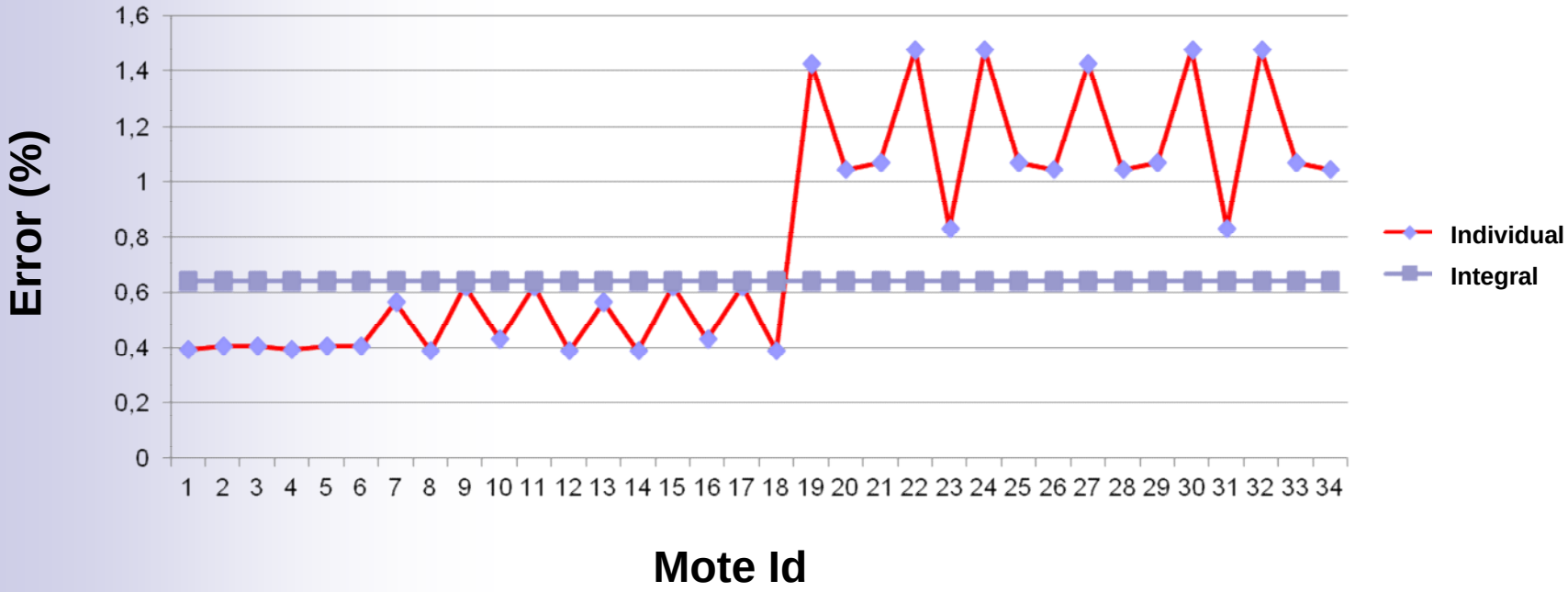

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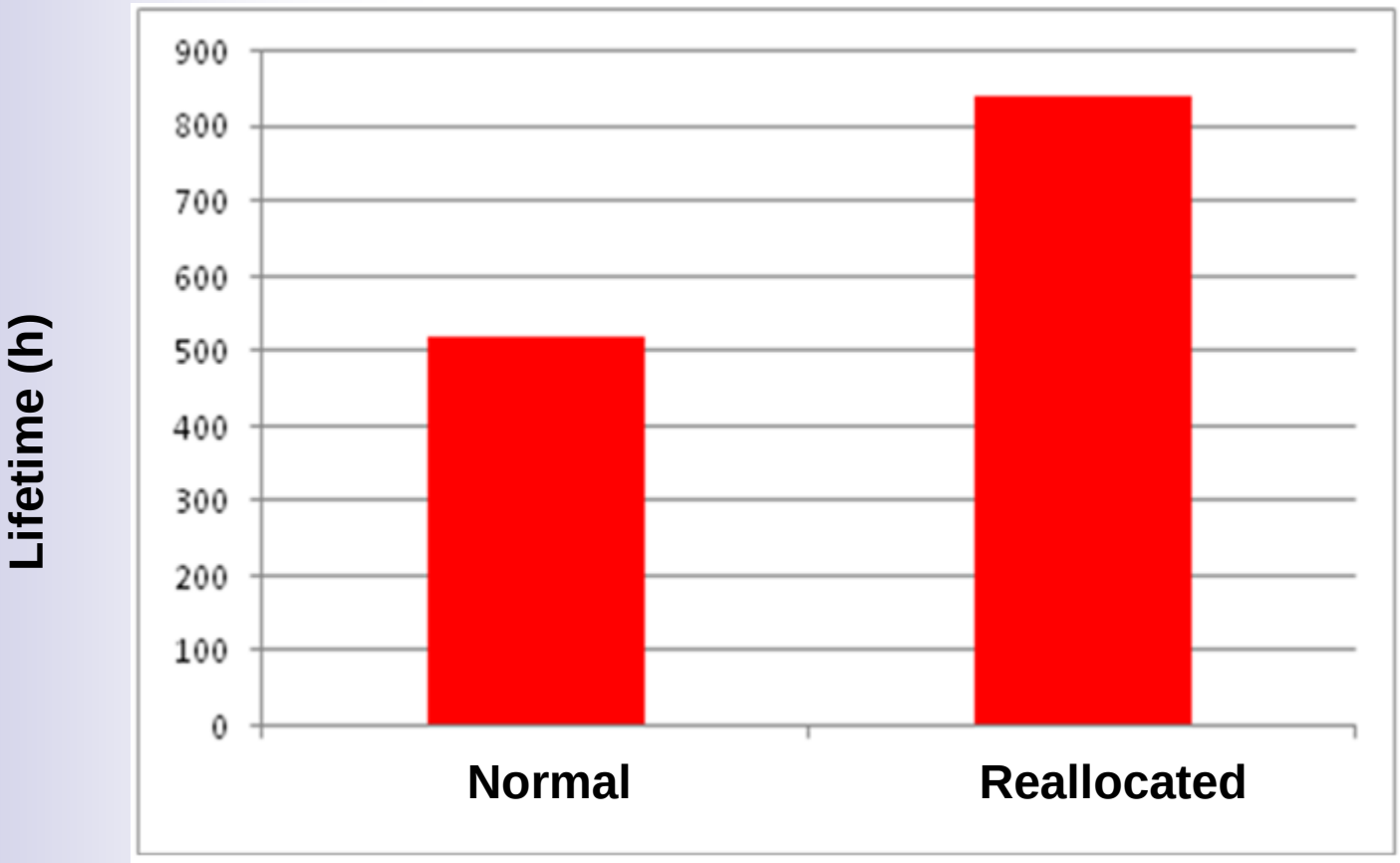
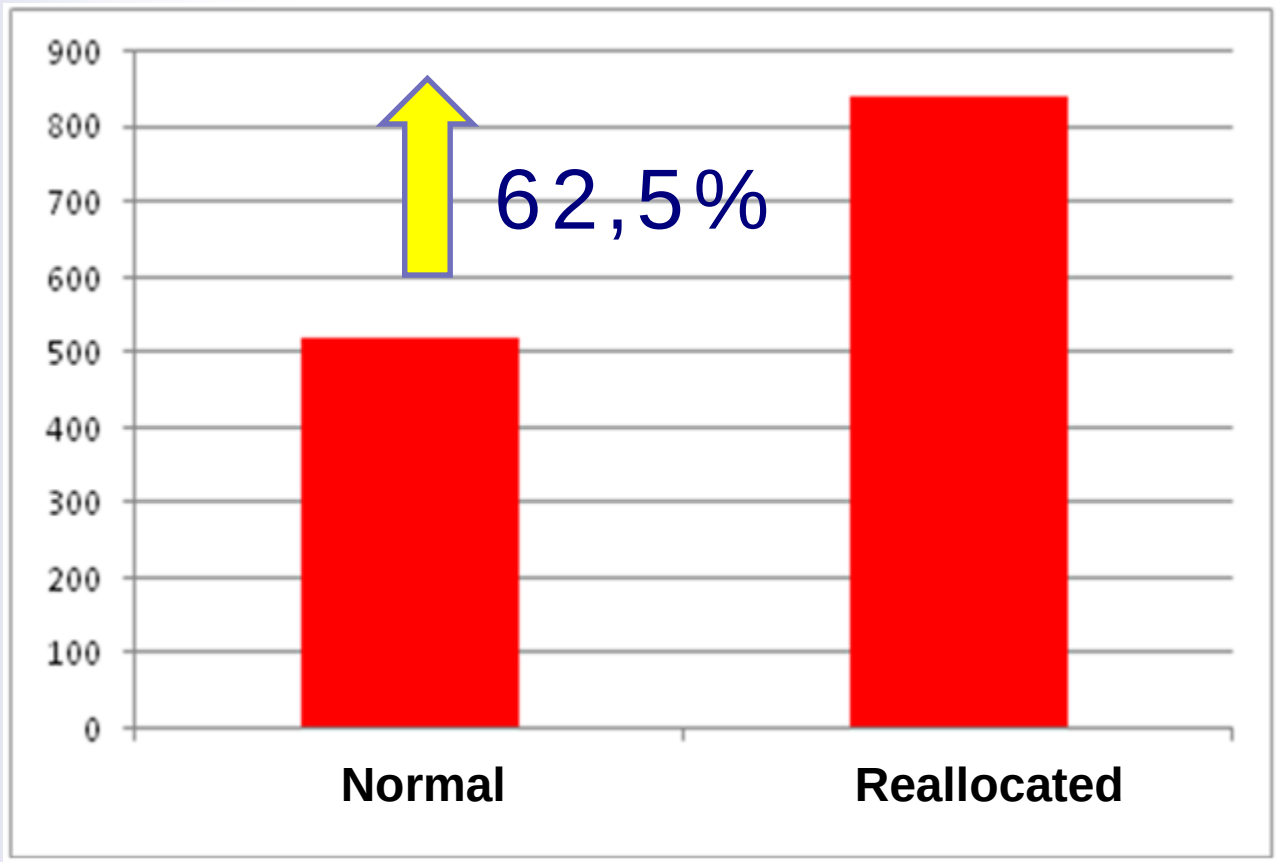


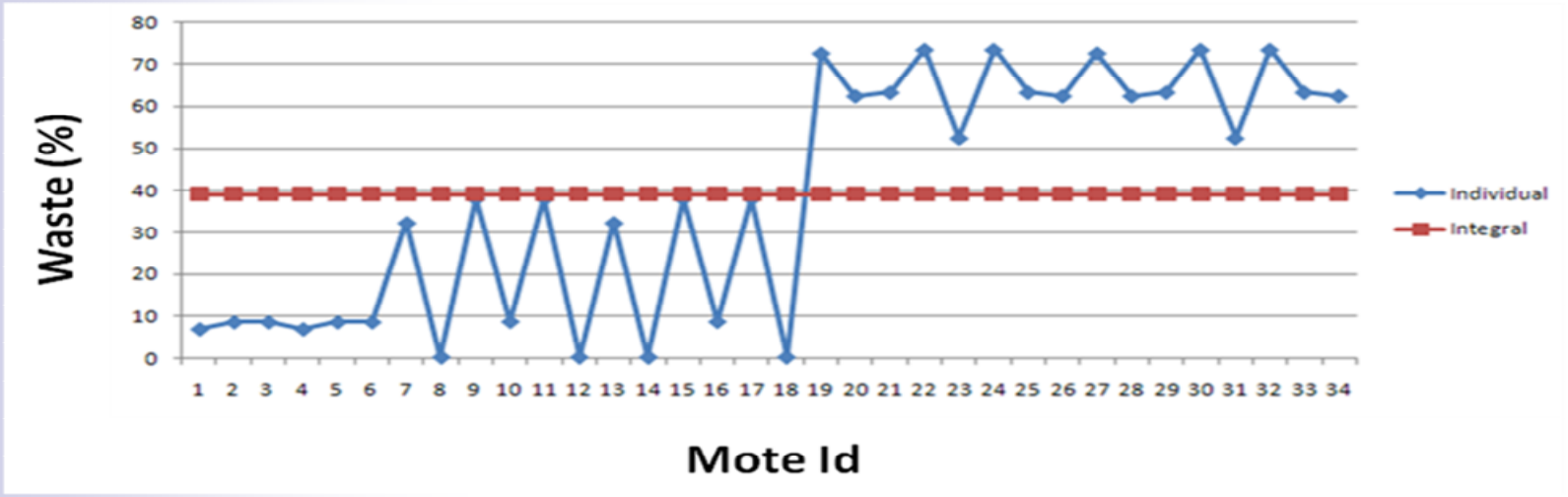
520 h x 840 h

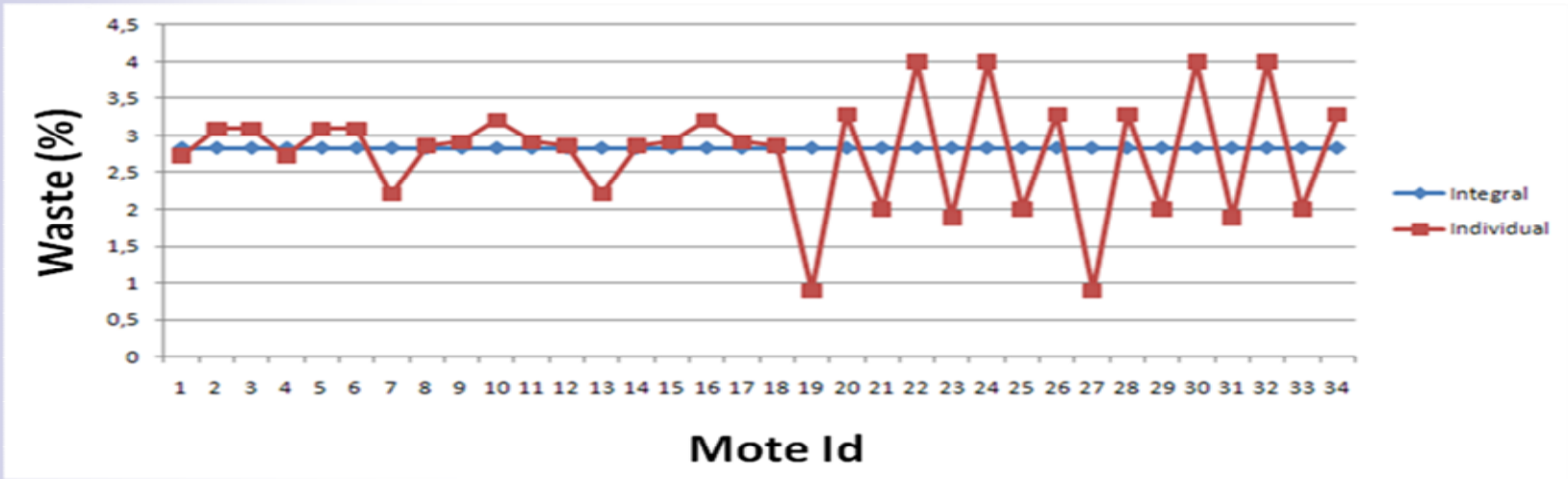
Validation



520 h x 840 h

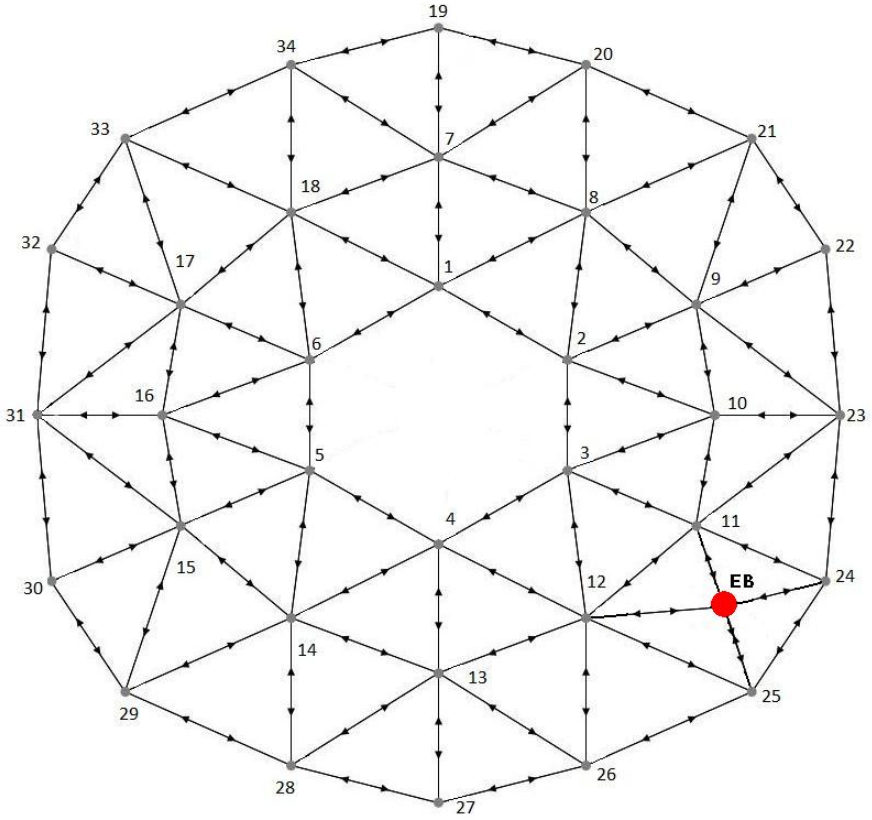
Validation
Energy Waste





Validation

- **Displaced Base Station**
  - **“Light case” of an irregular topology**



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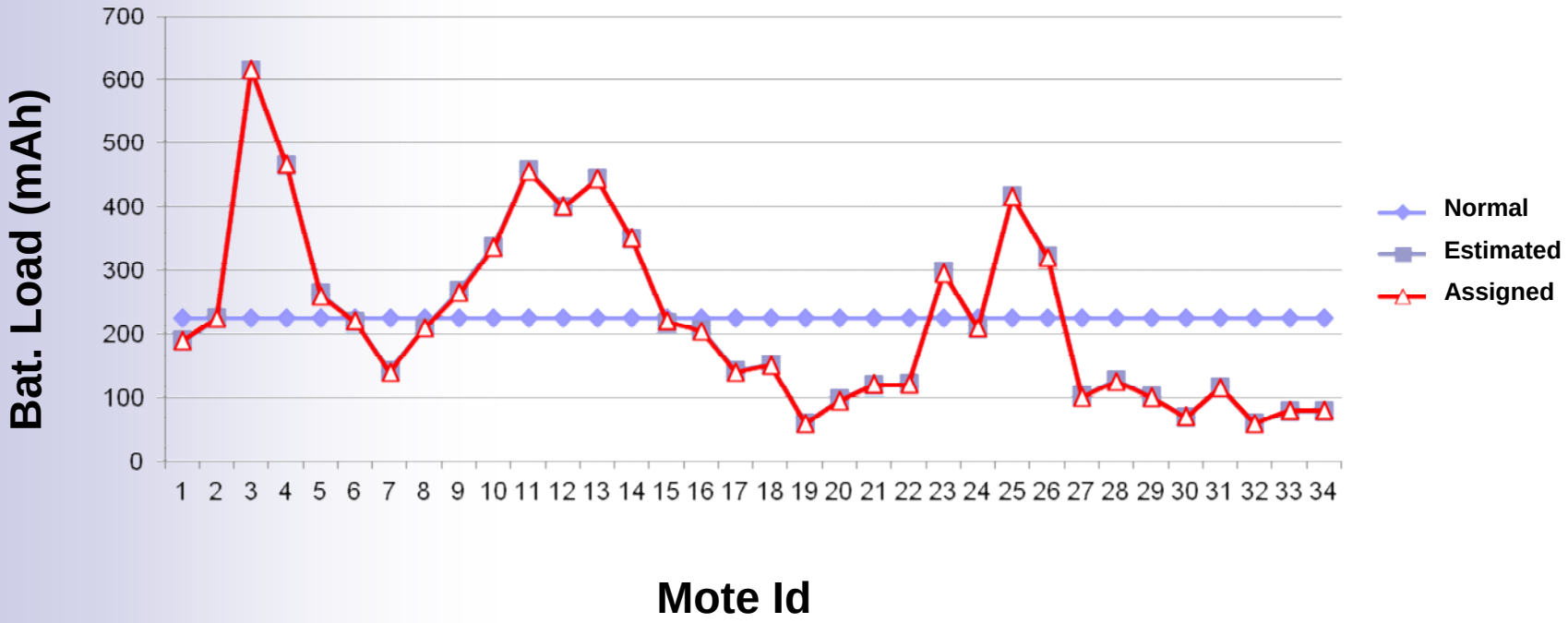

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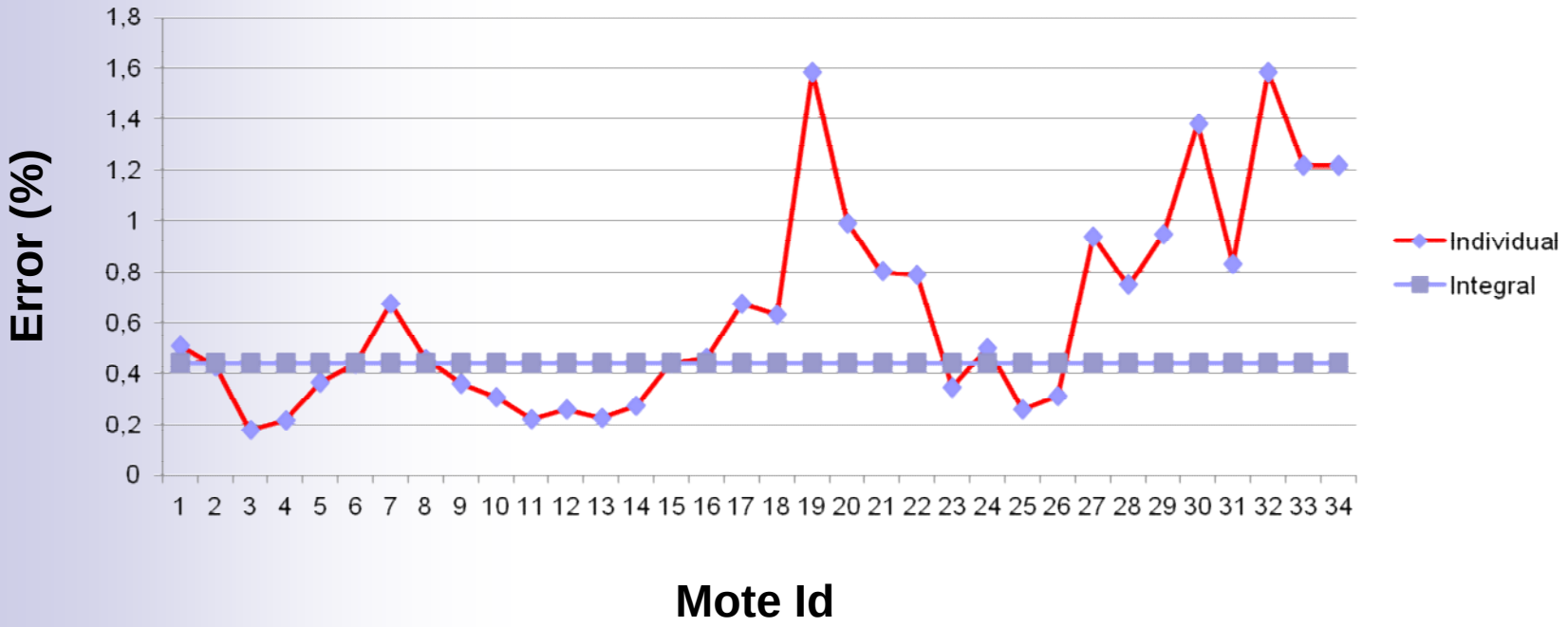

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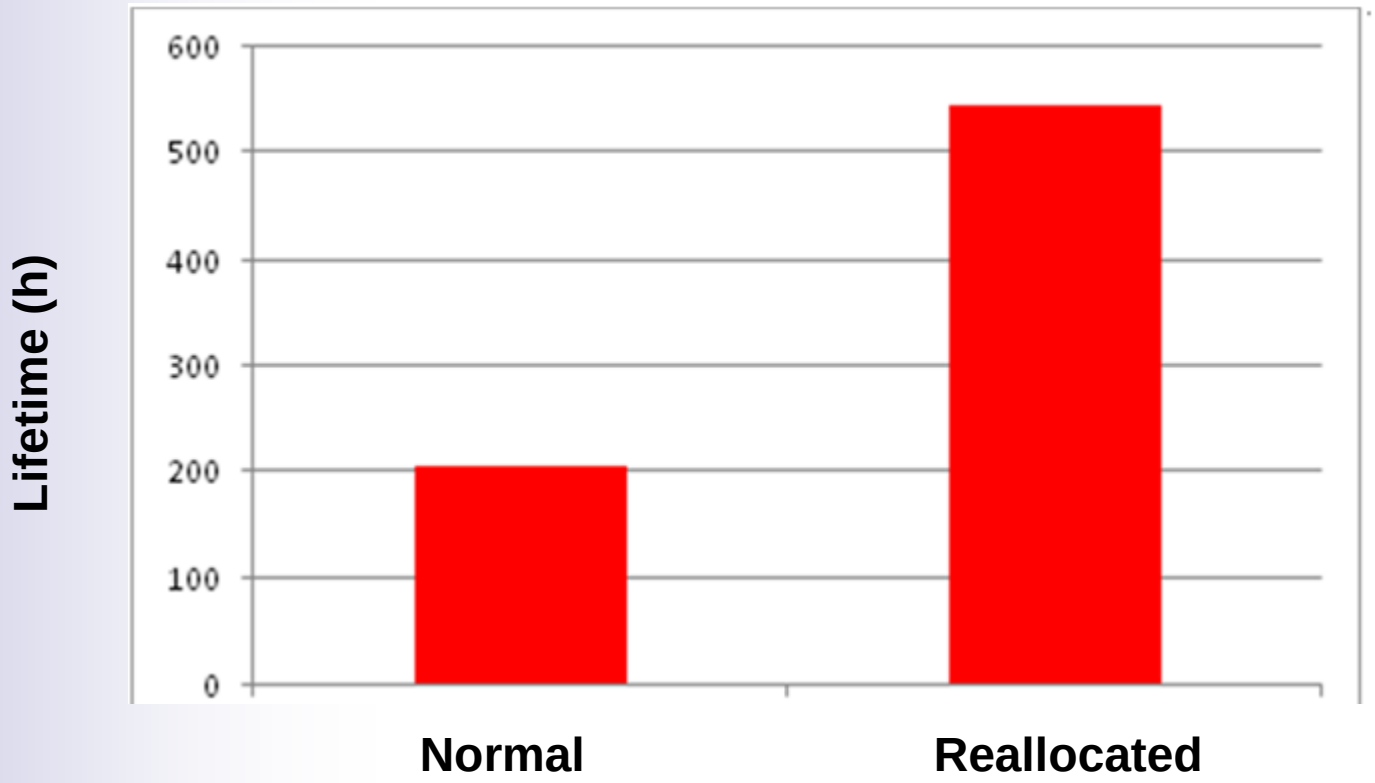

205,6 h x 545,75 h

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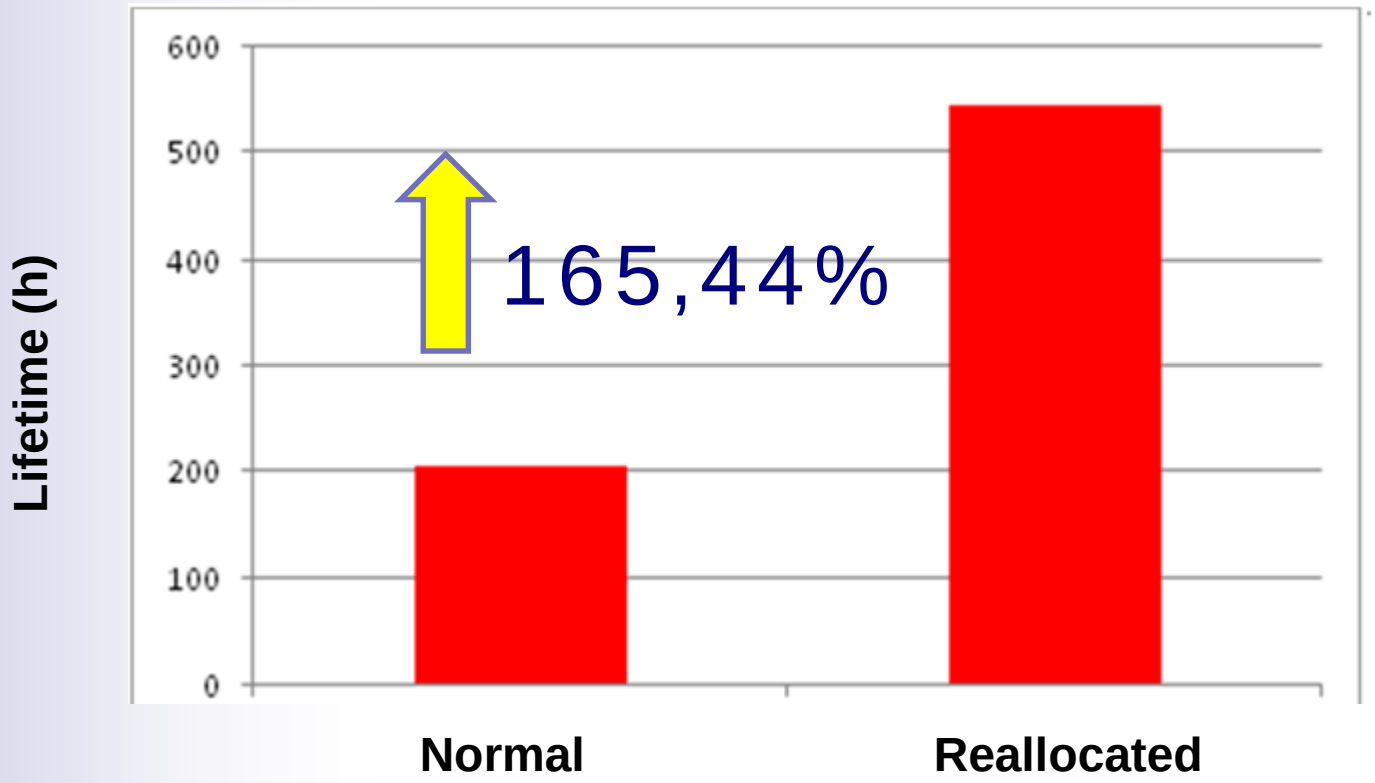

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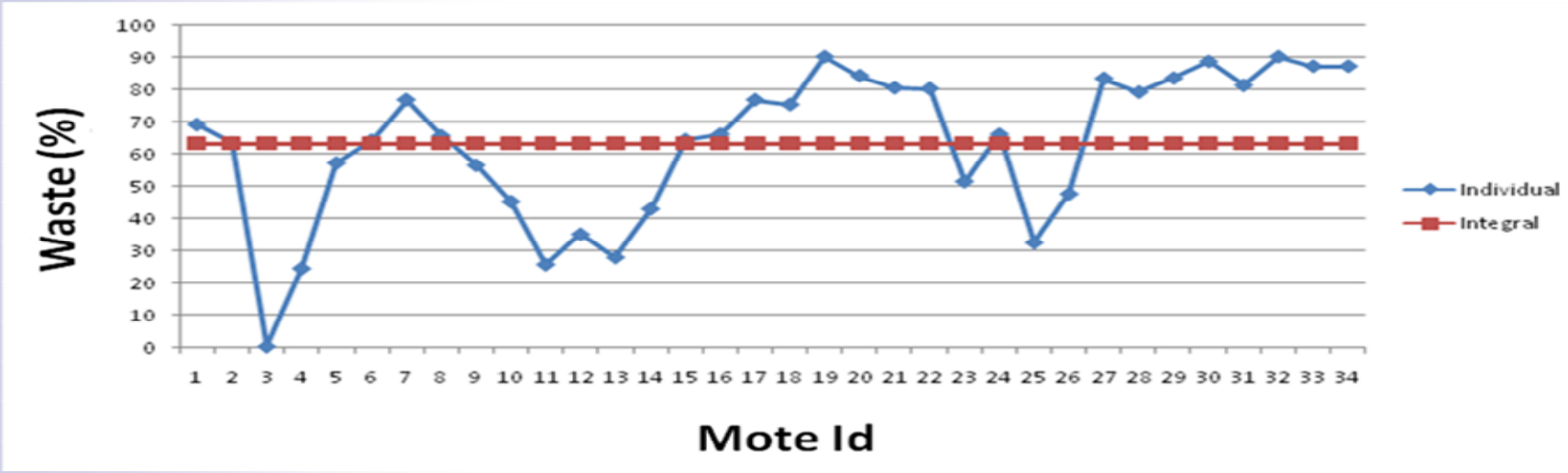

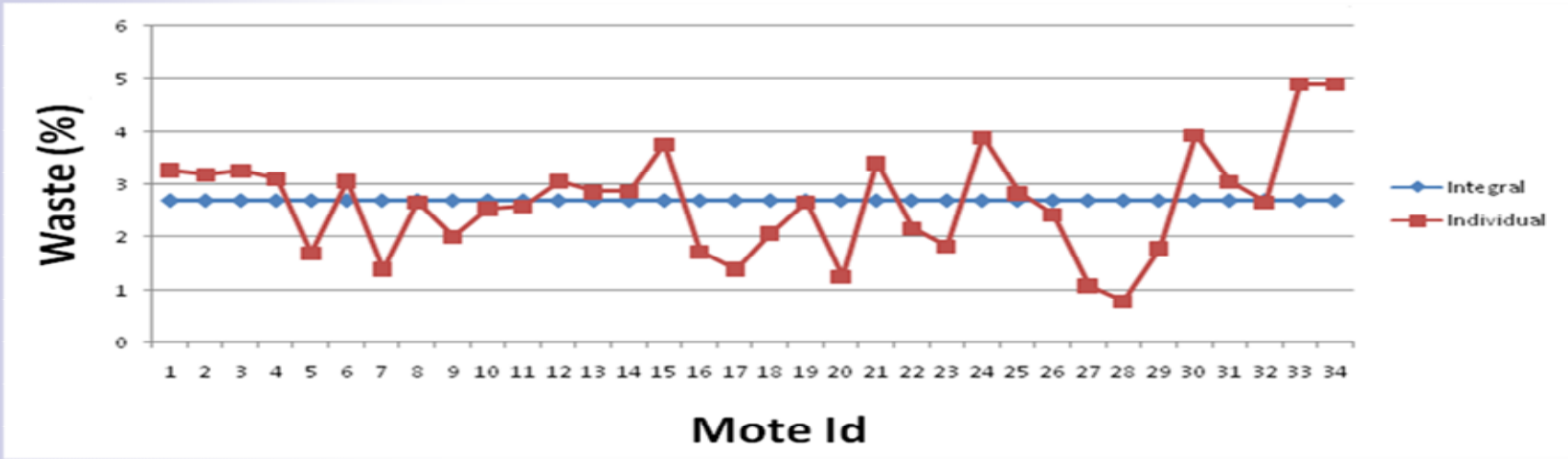

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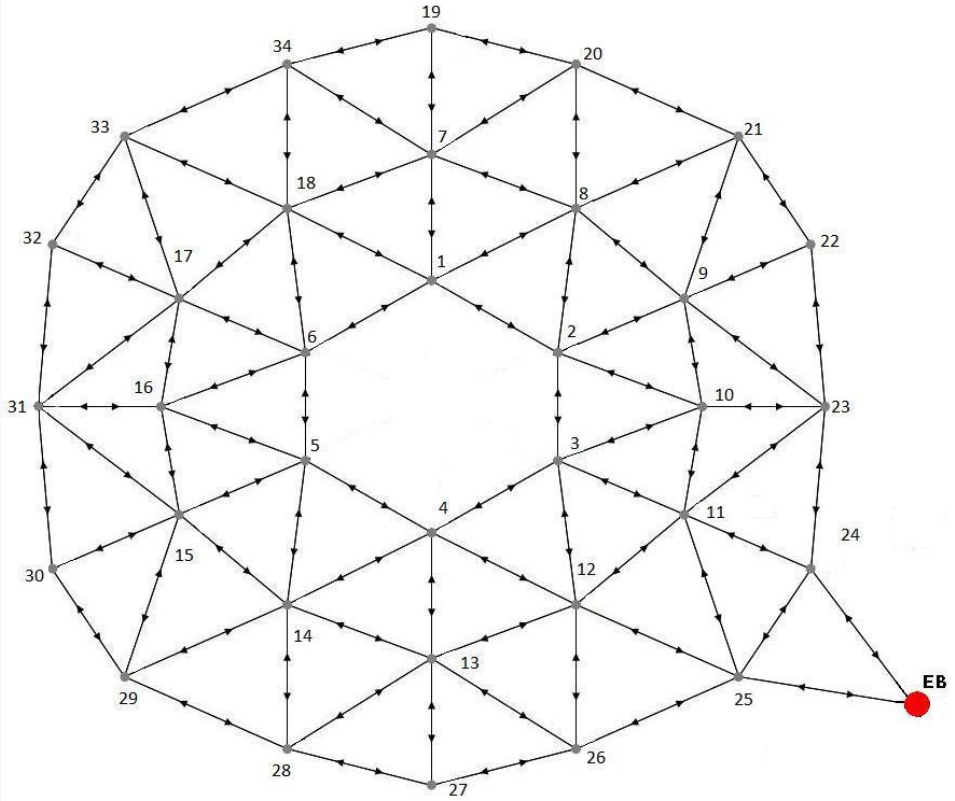

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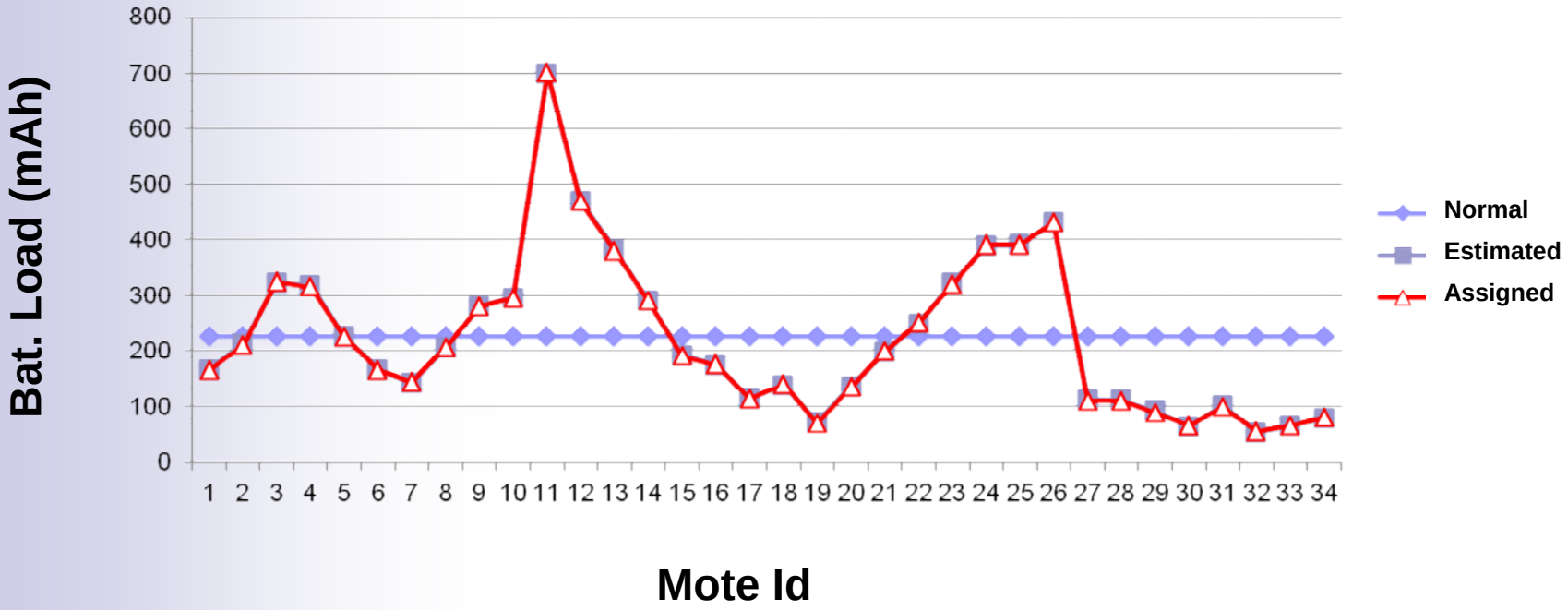

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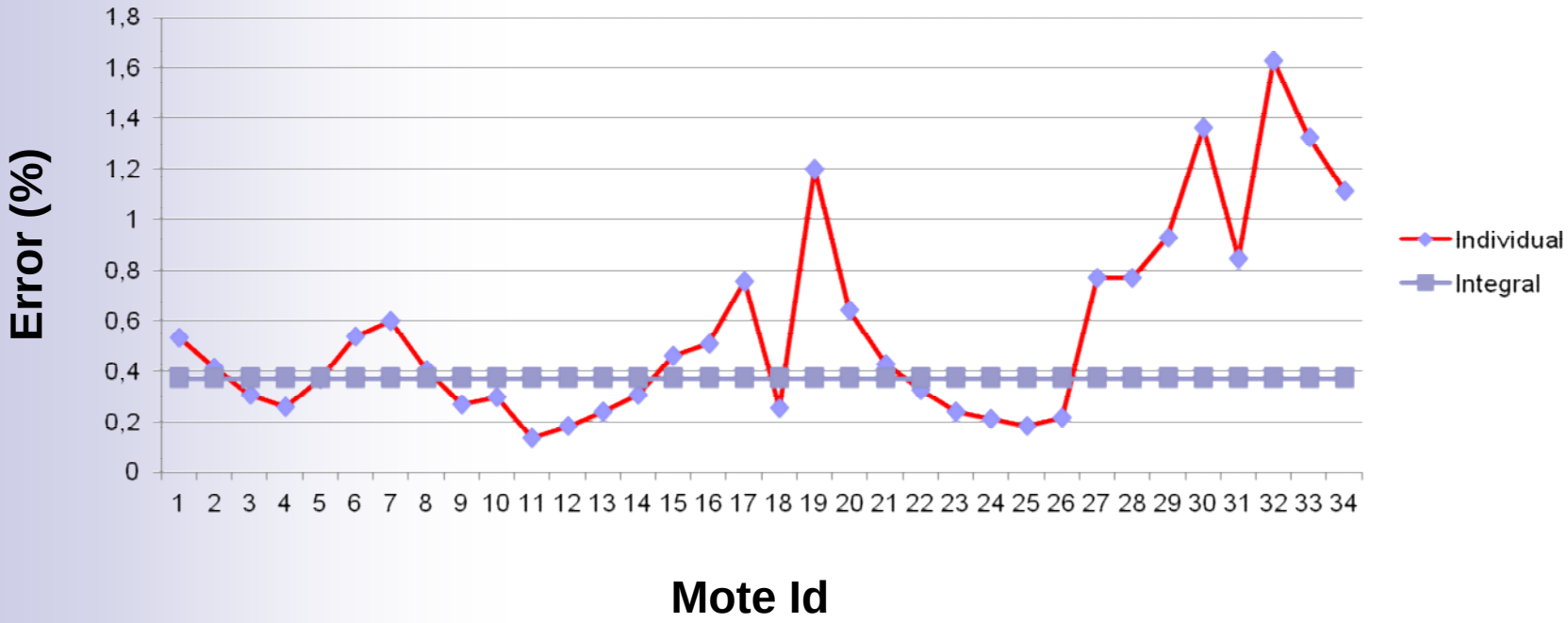

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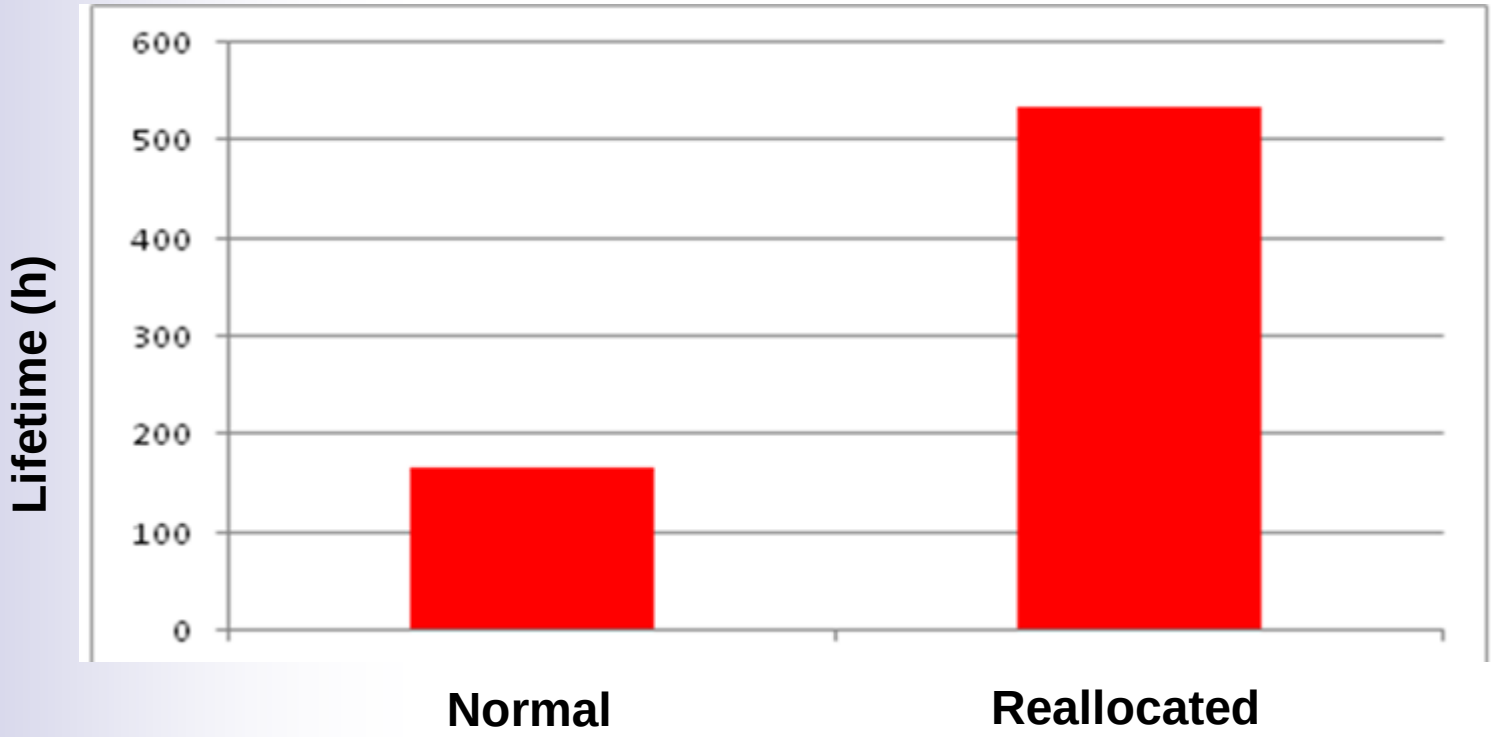
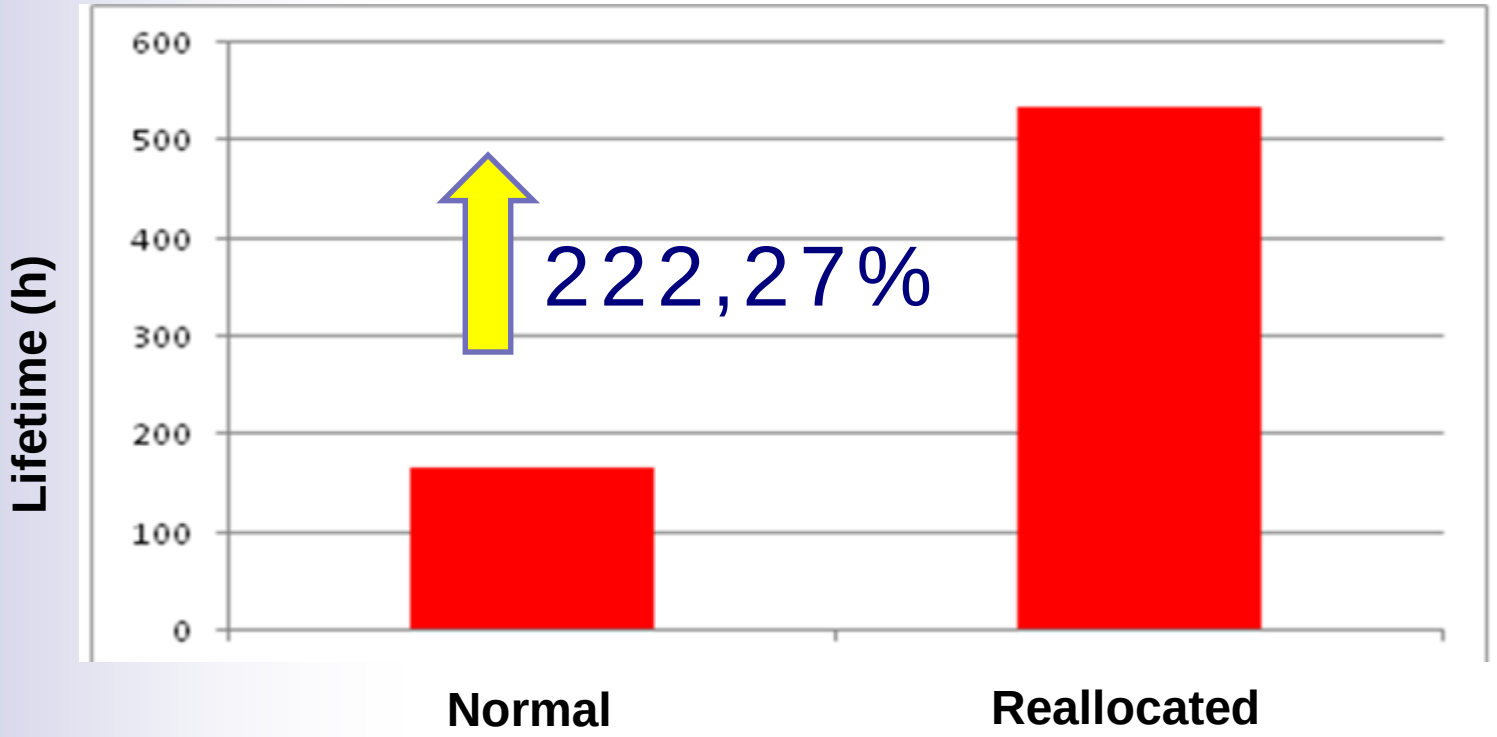


165,93 h x 534,75 h

Validation



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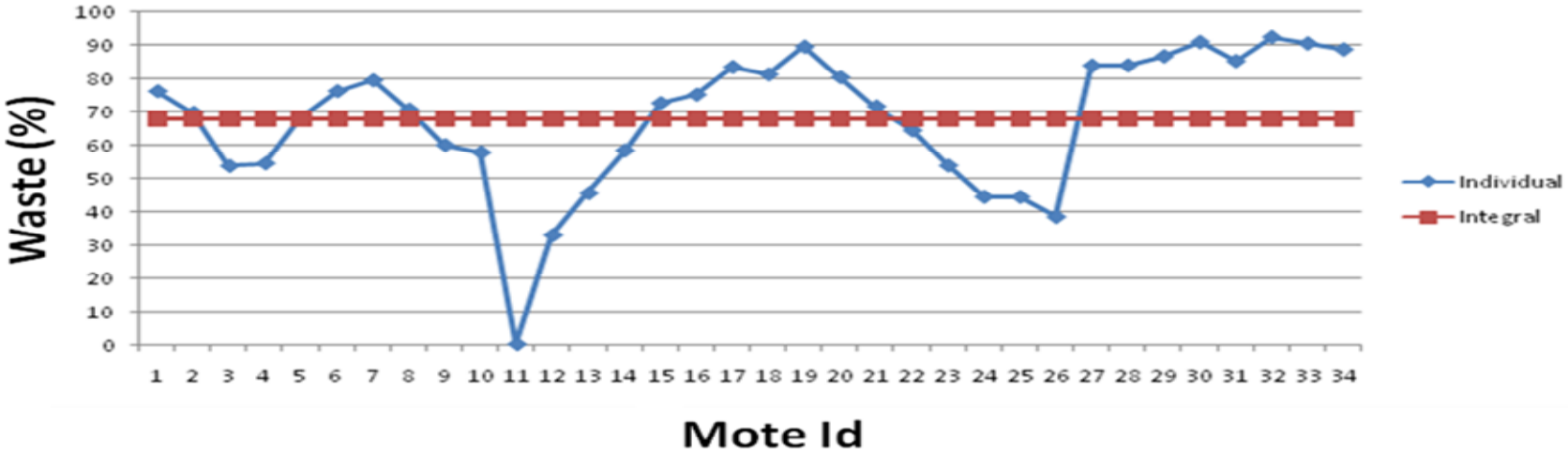

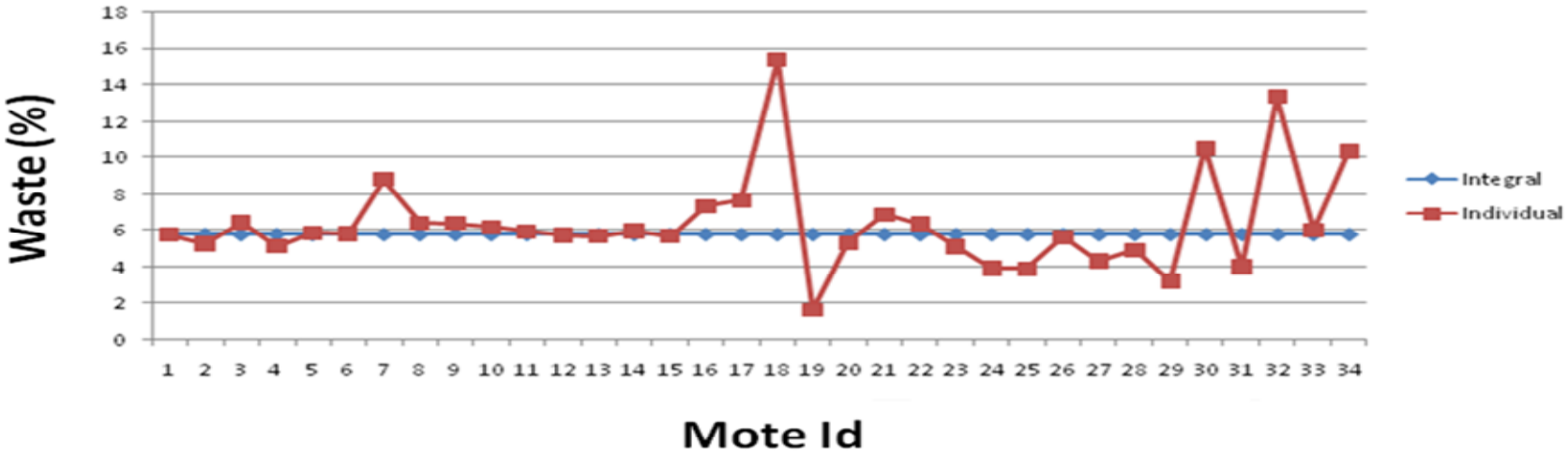

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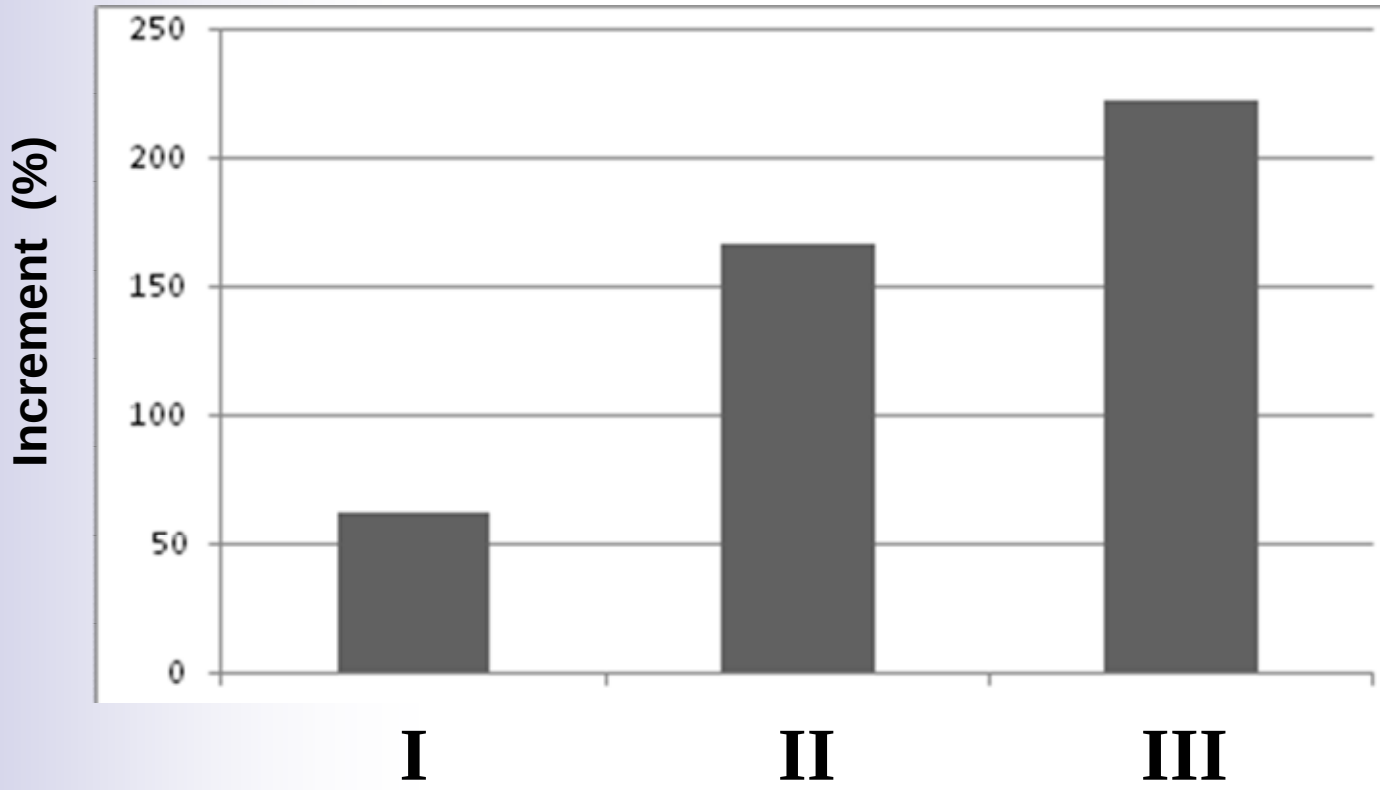
Lifetime Increment



Simulations using IEEE 802.11 RTS/CTS

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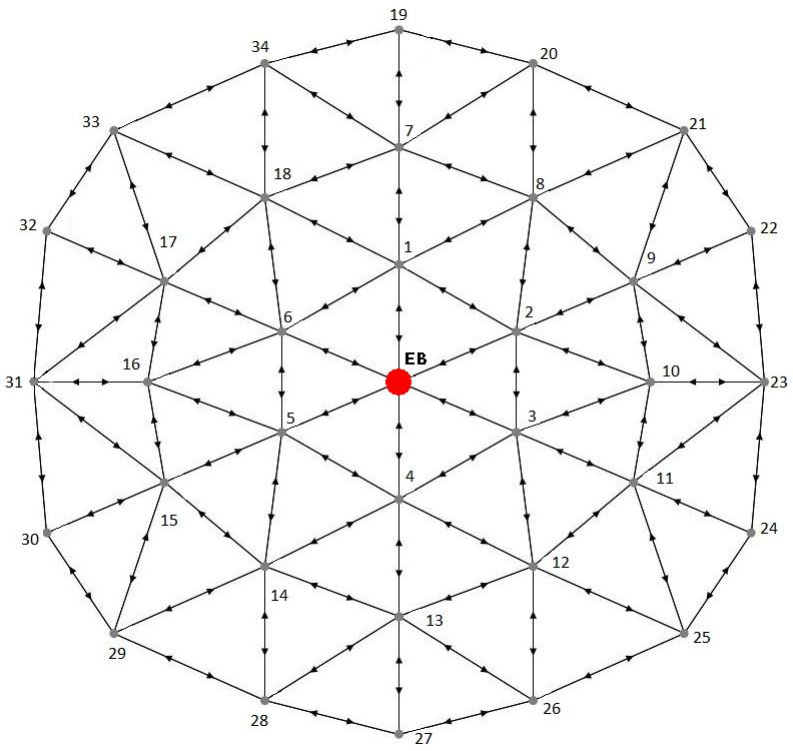

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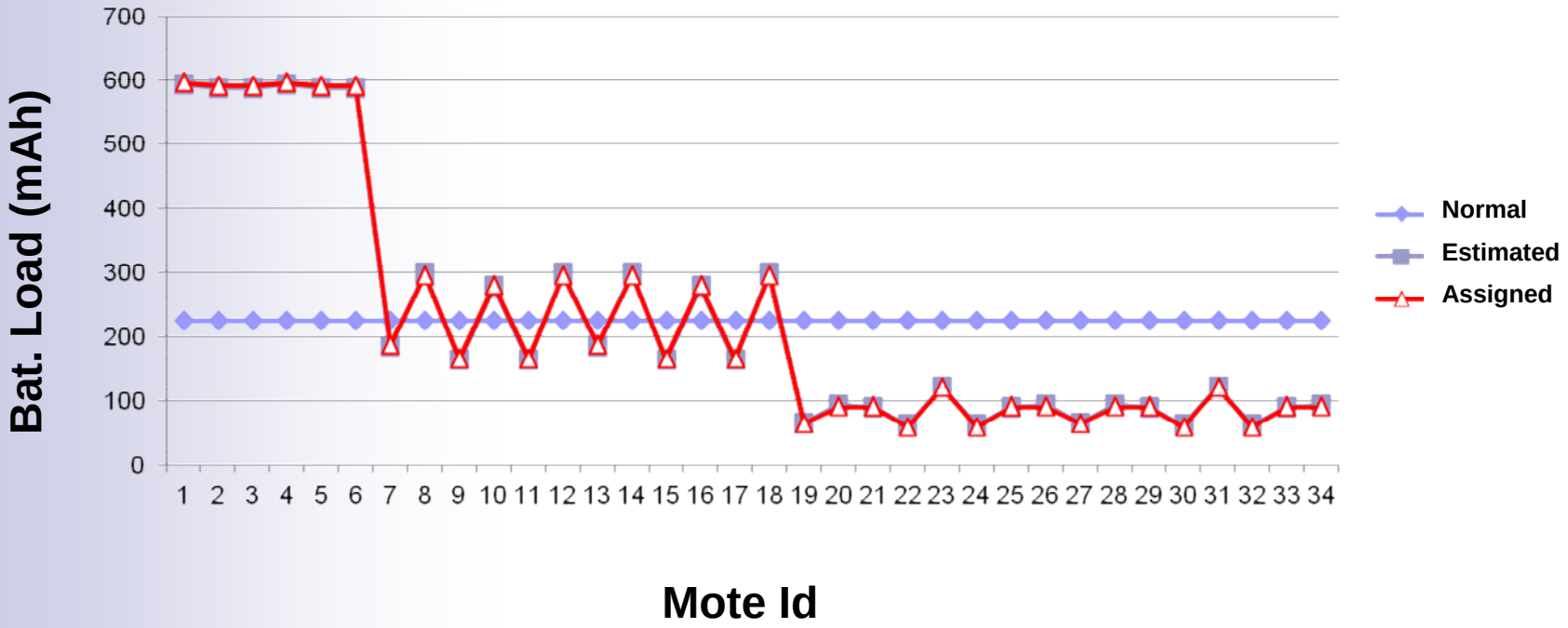

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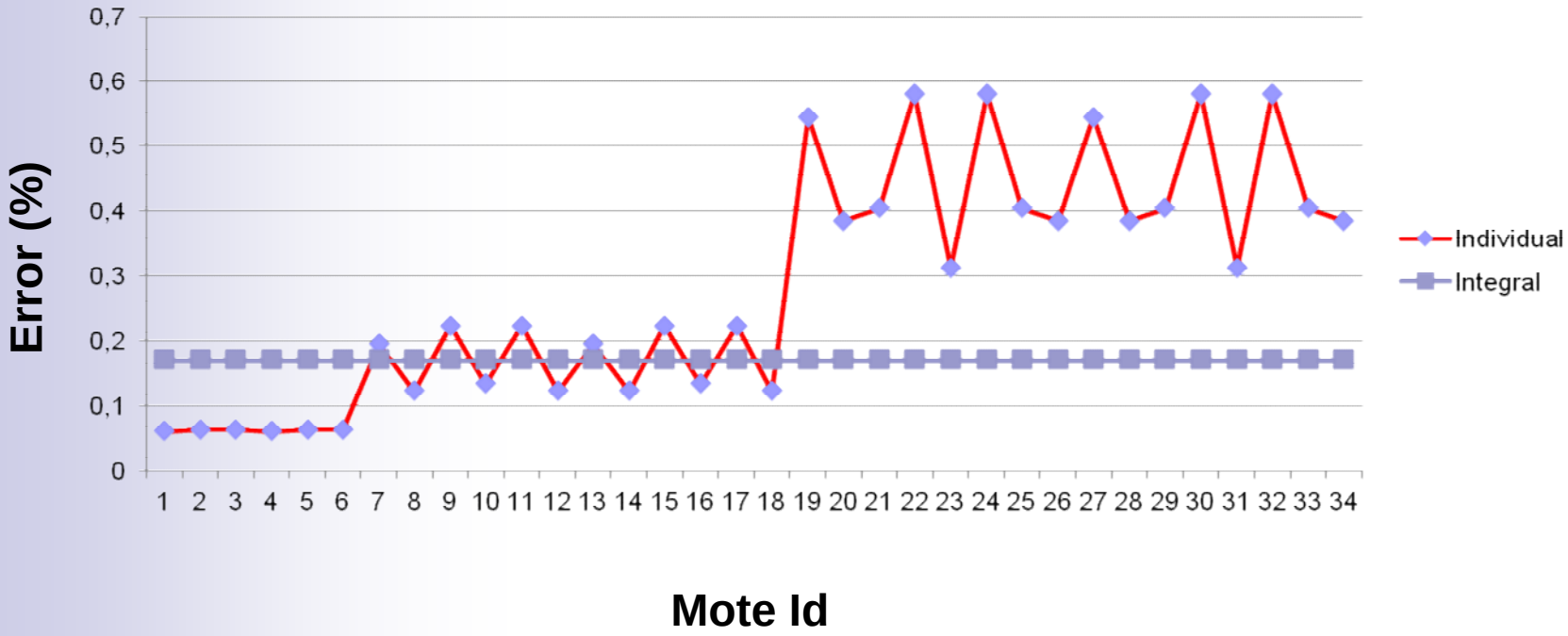

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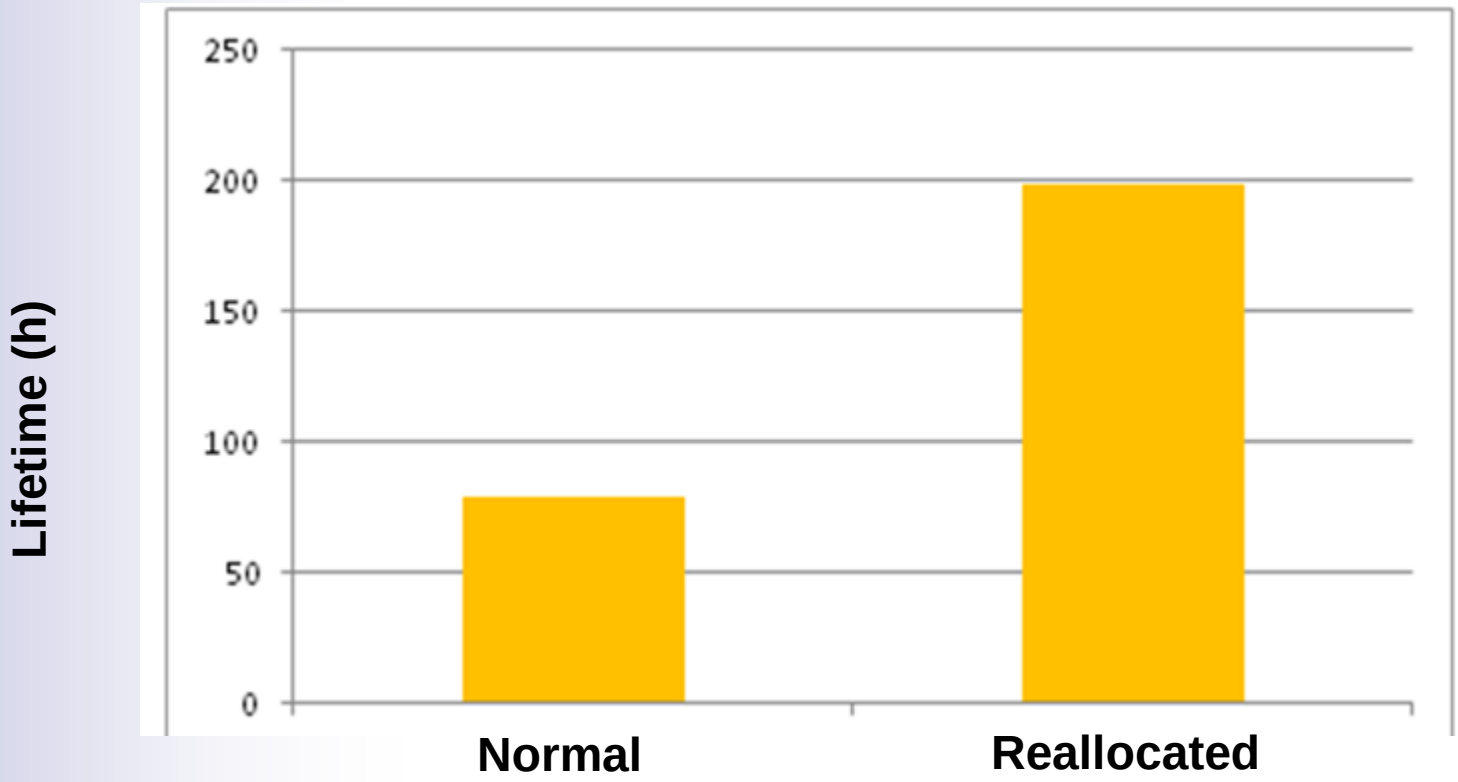

79,41 h x 198,08 h

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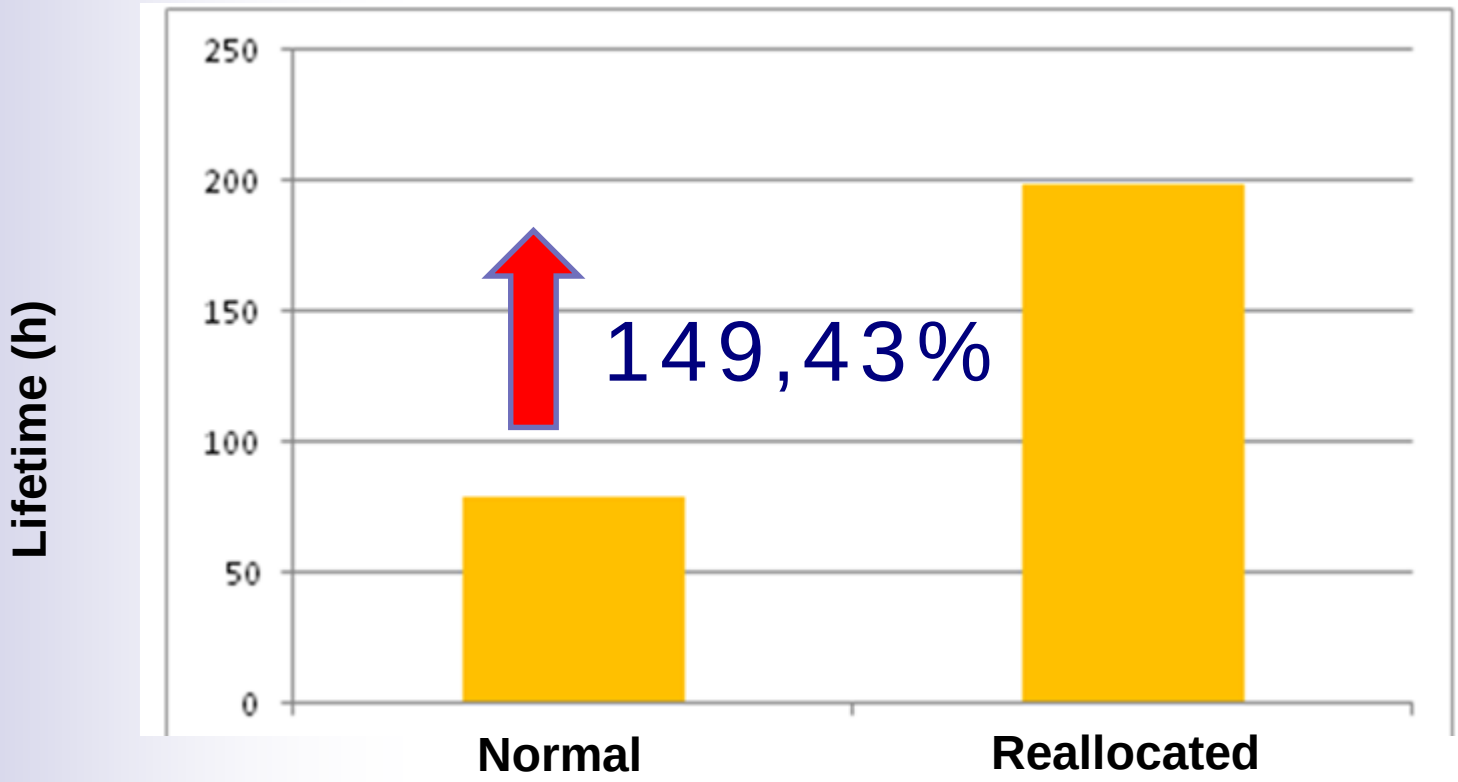

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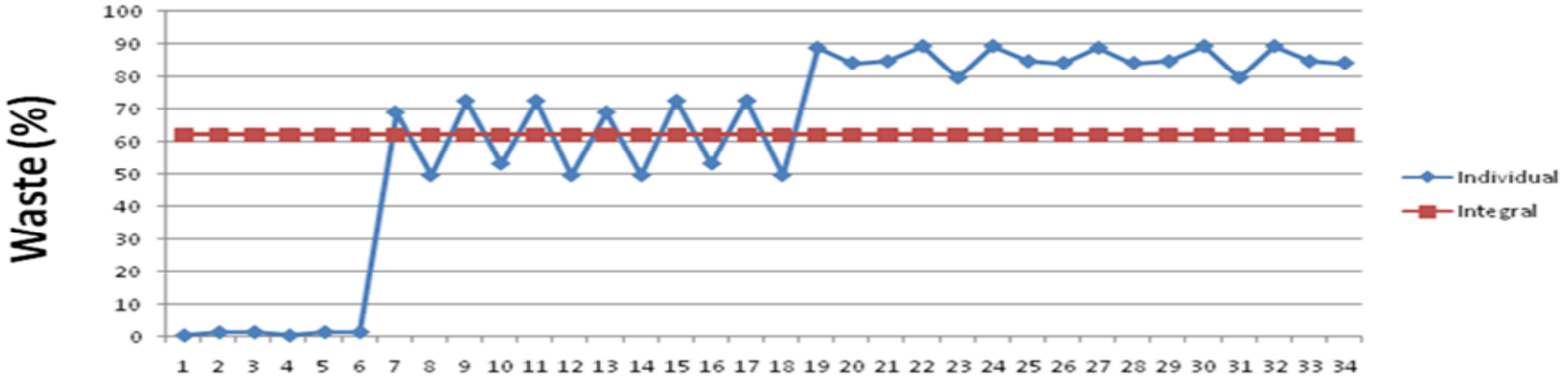

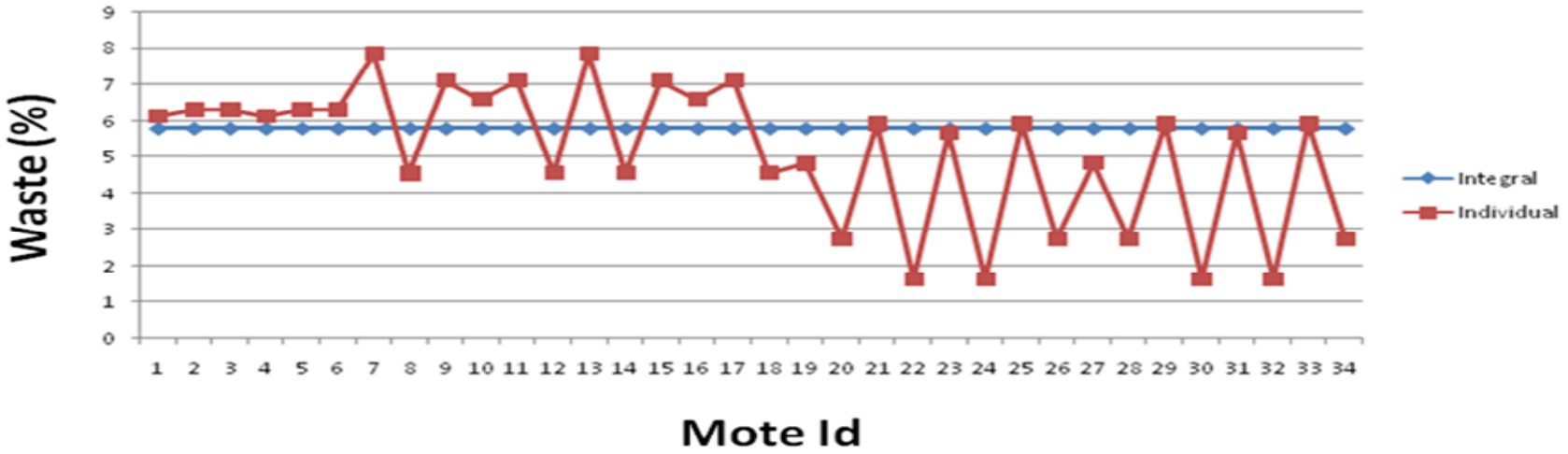

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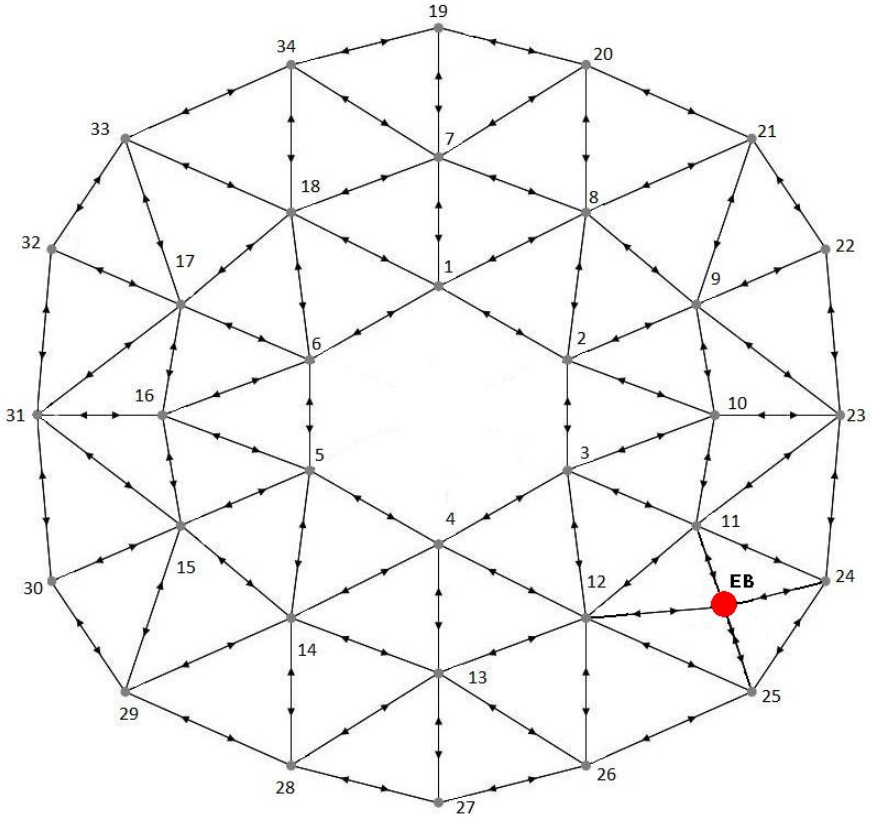

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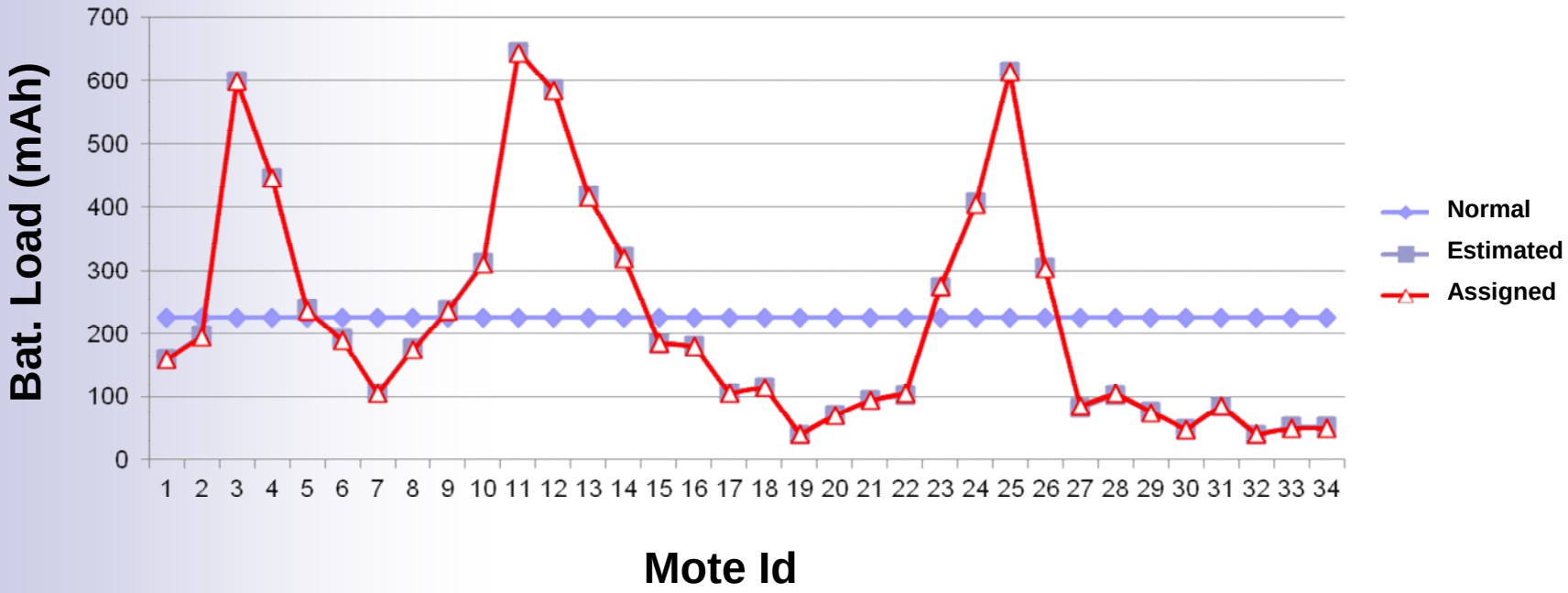

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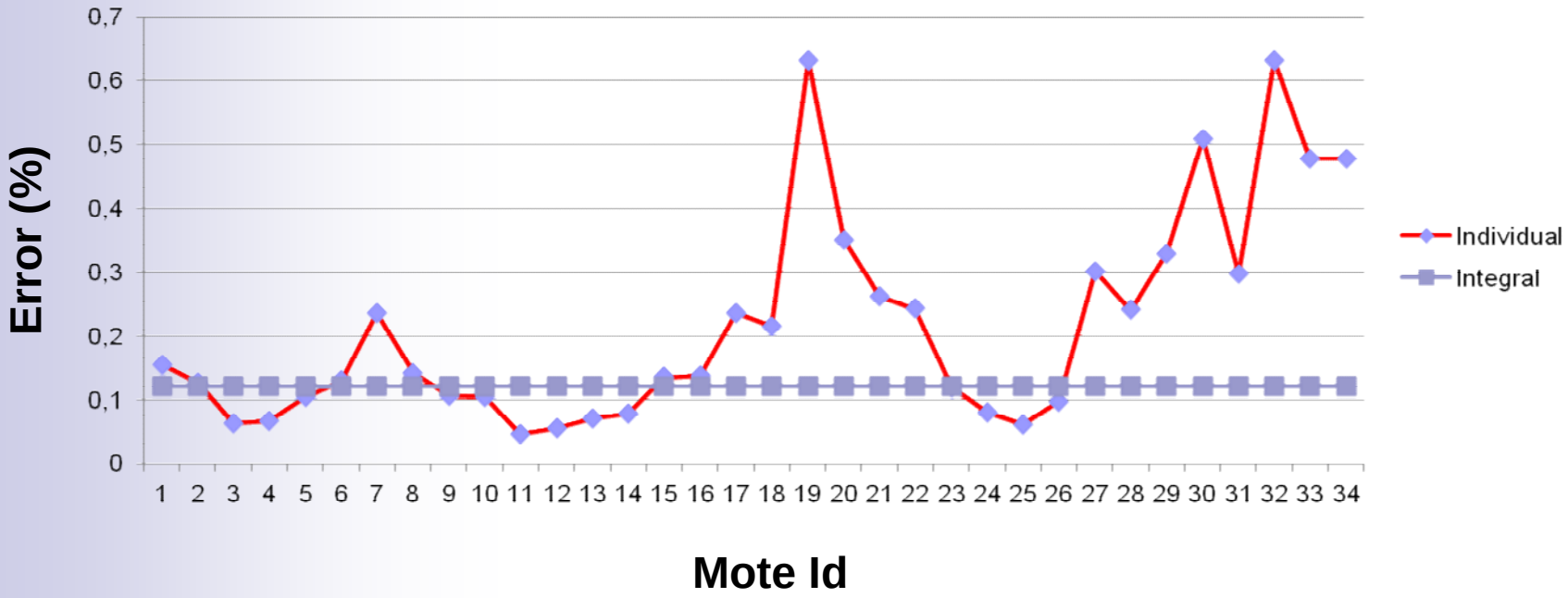

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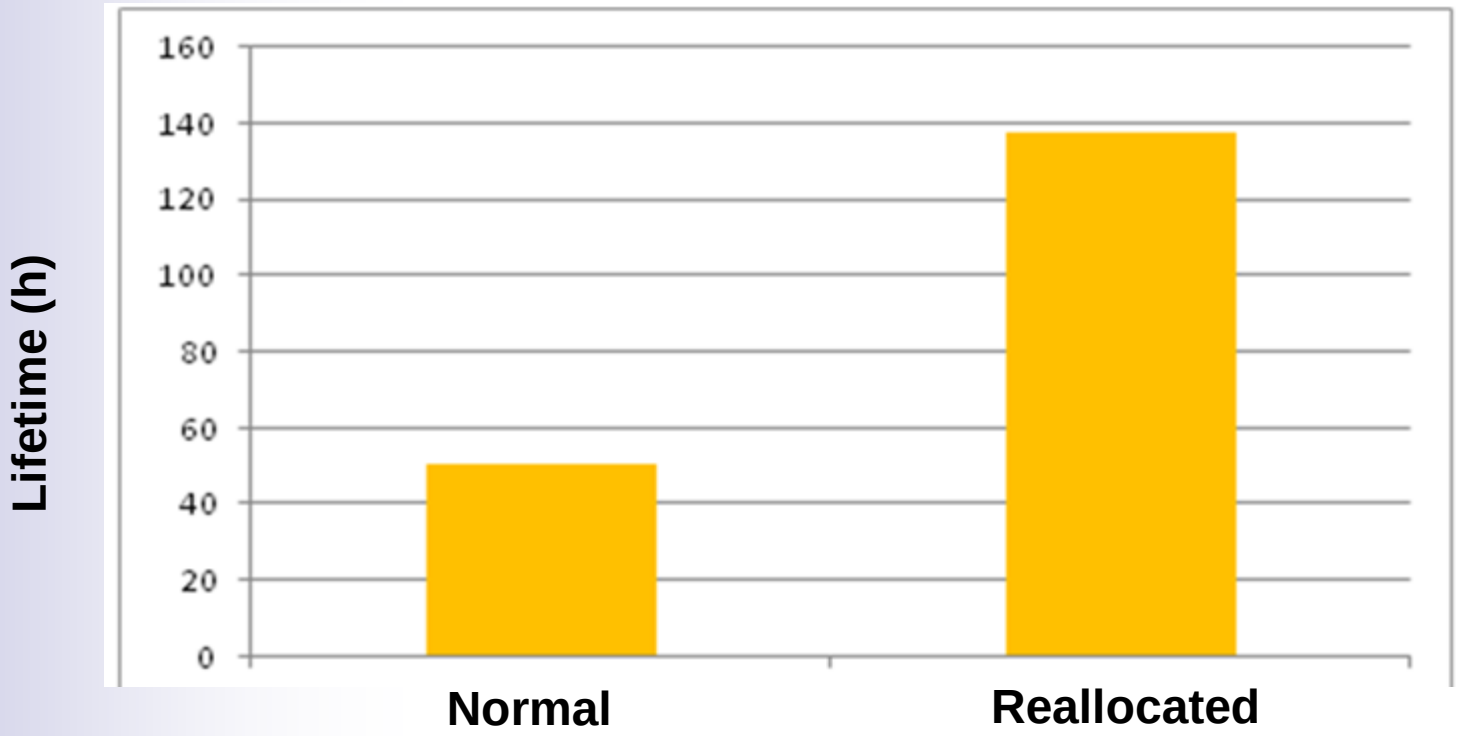
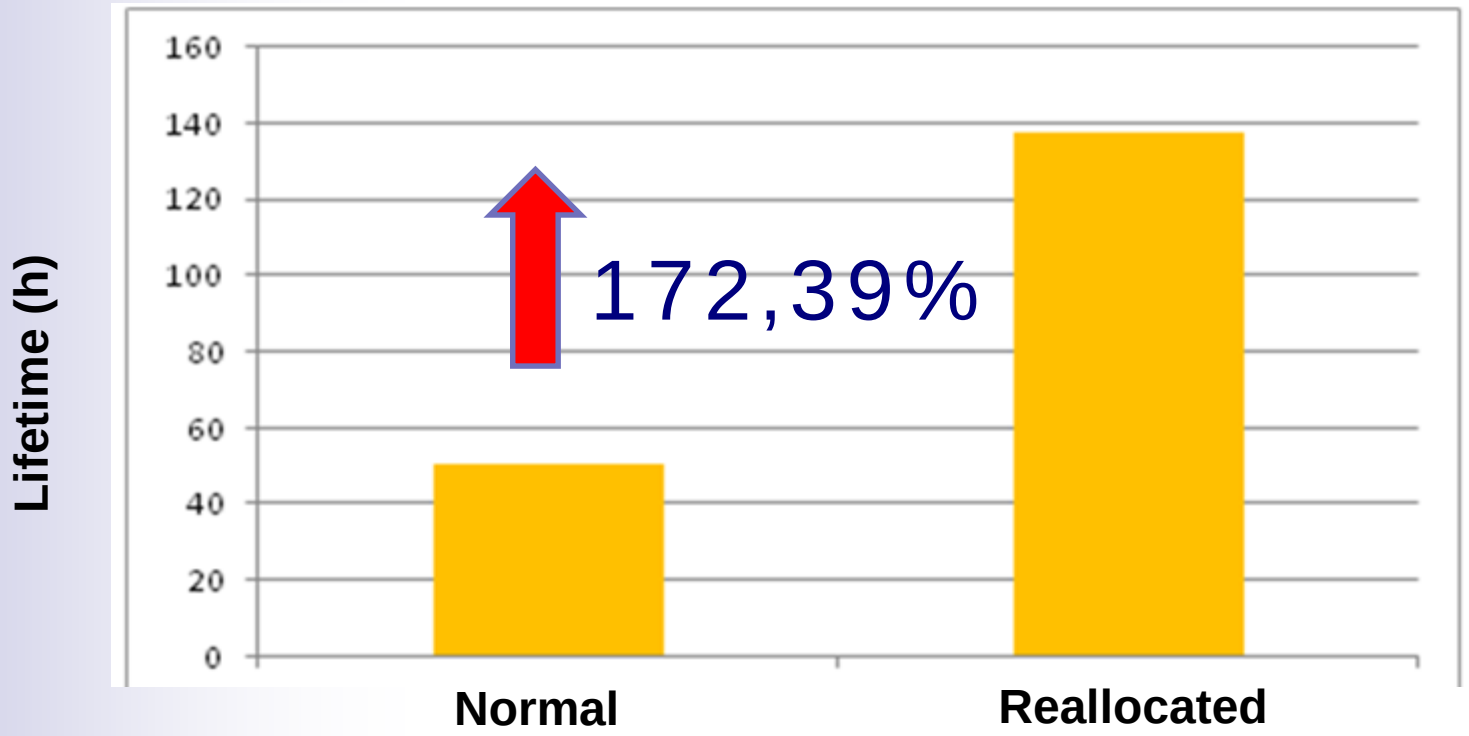


50,6 h x 137,83 h

Validation



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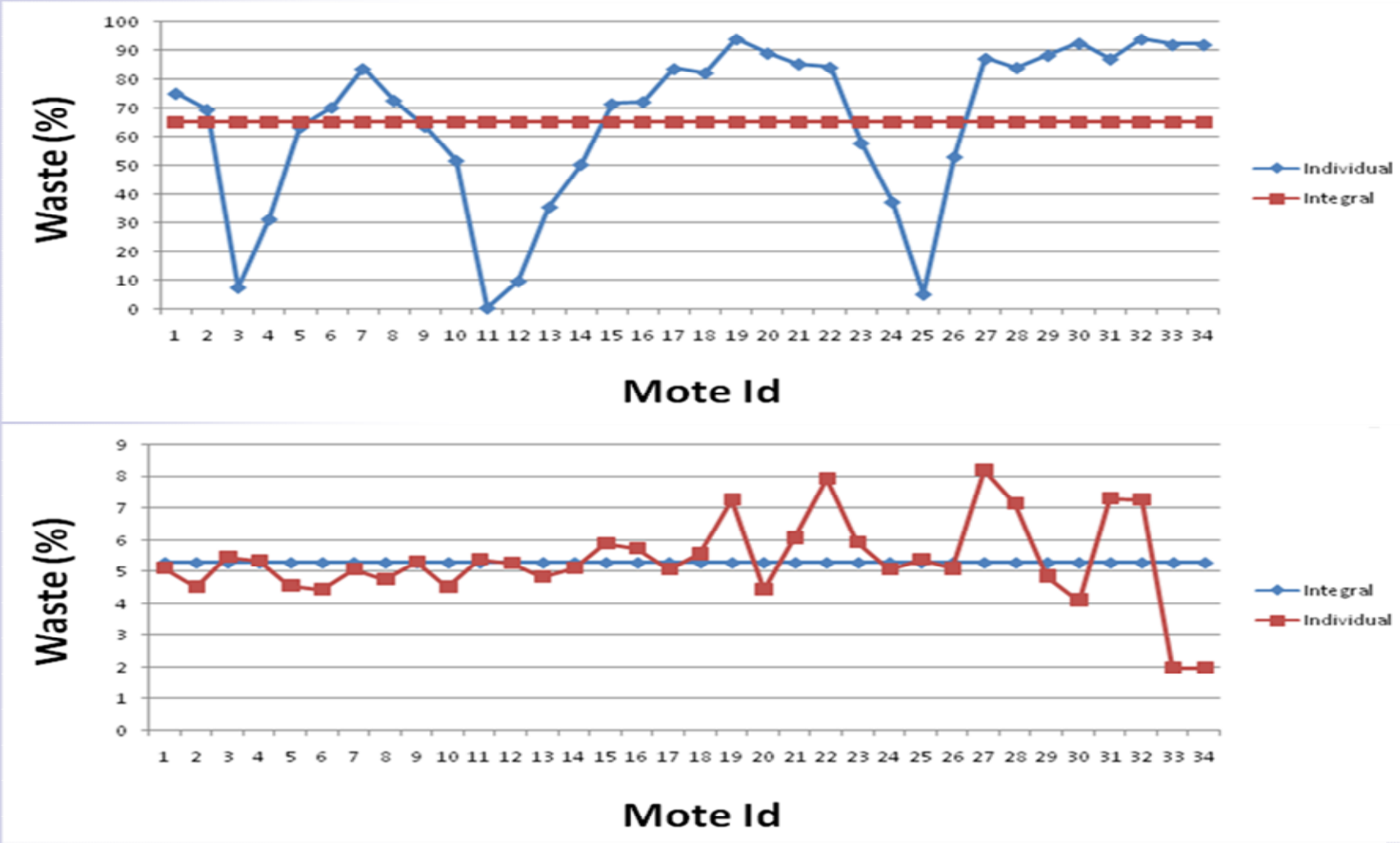

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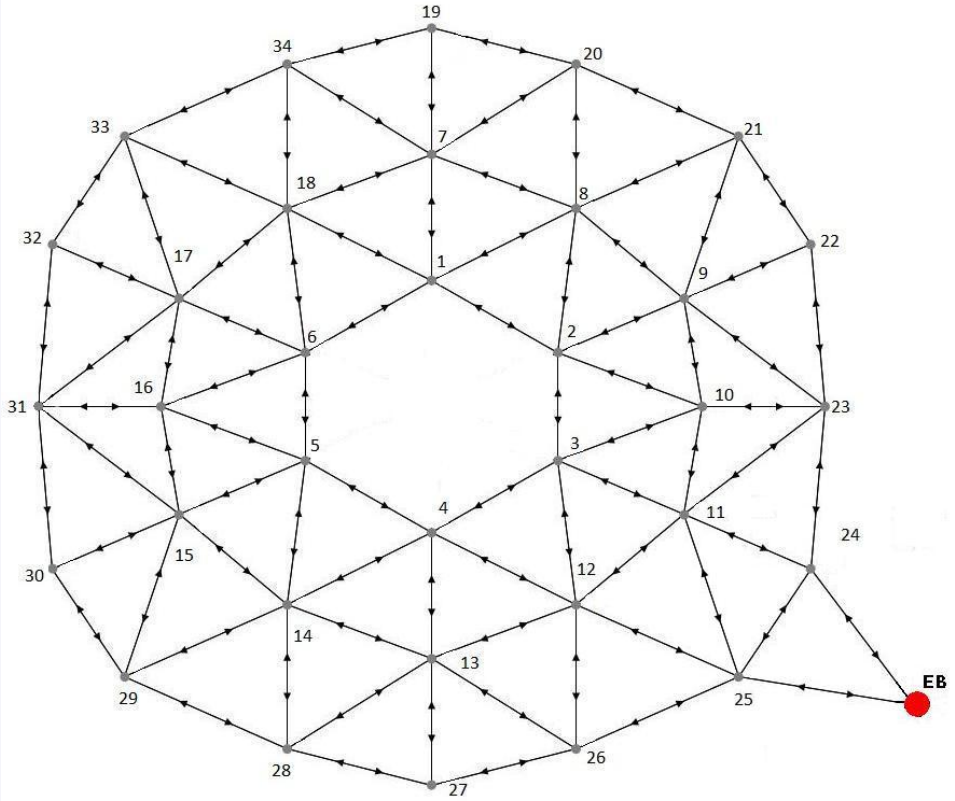

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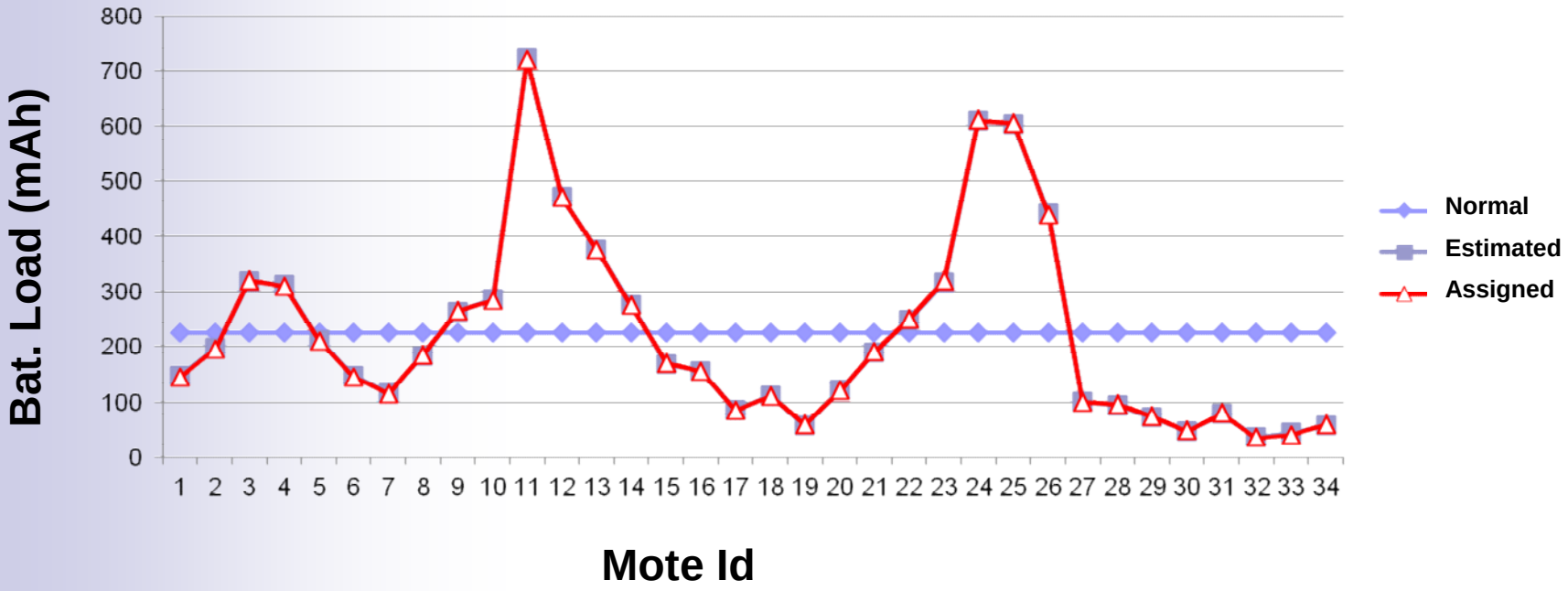

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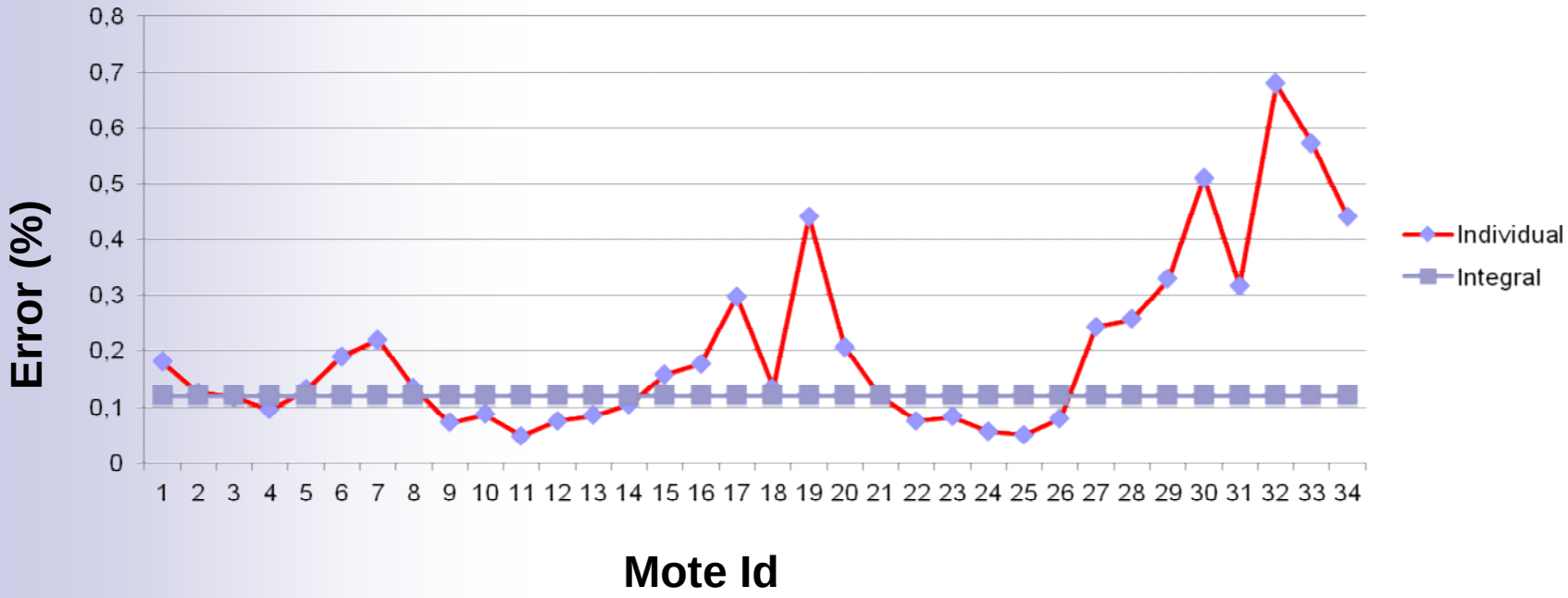

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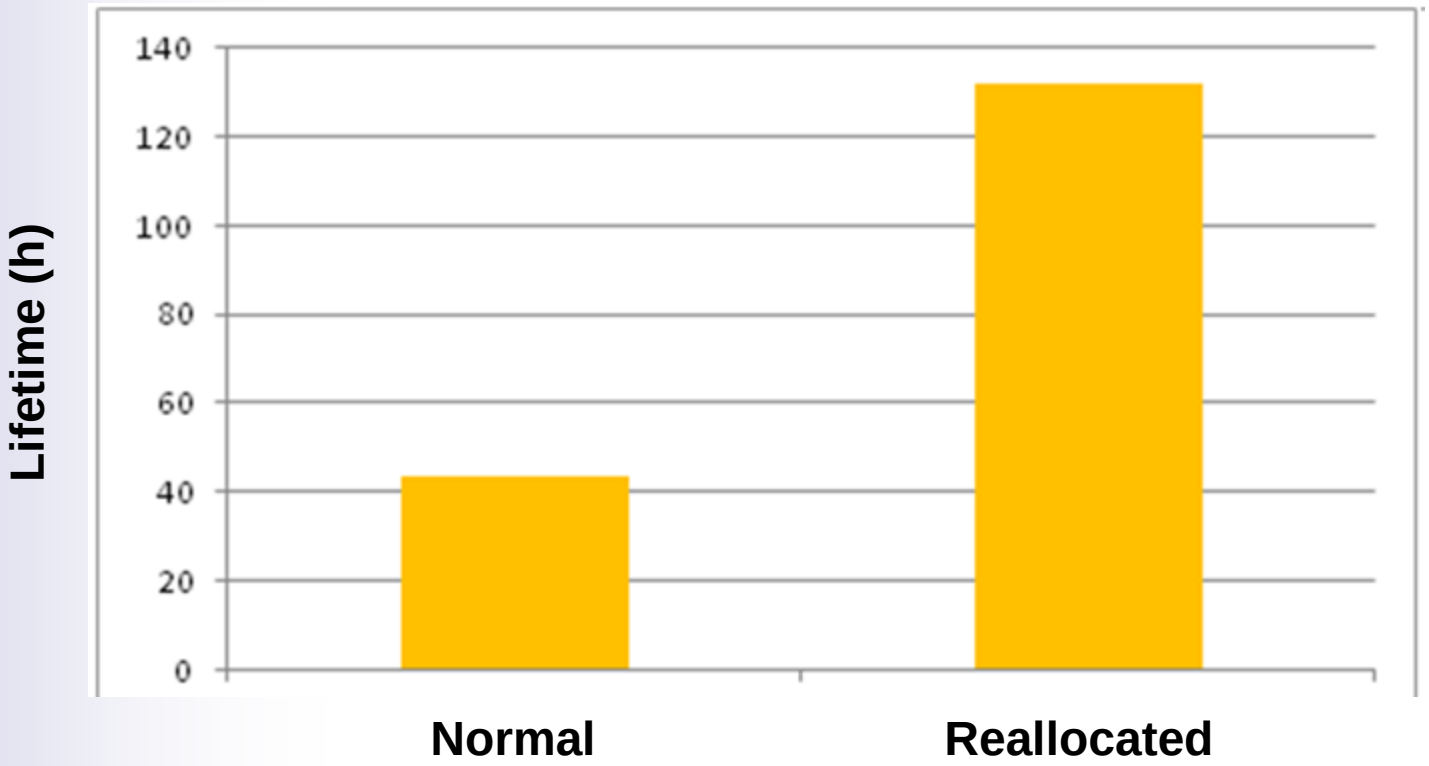

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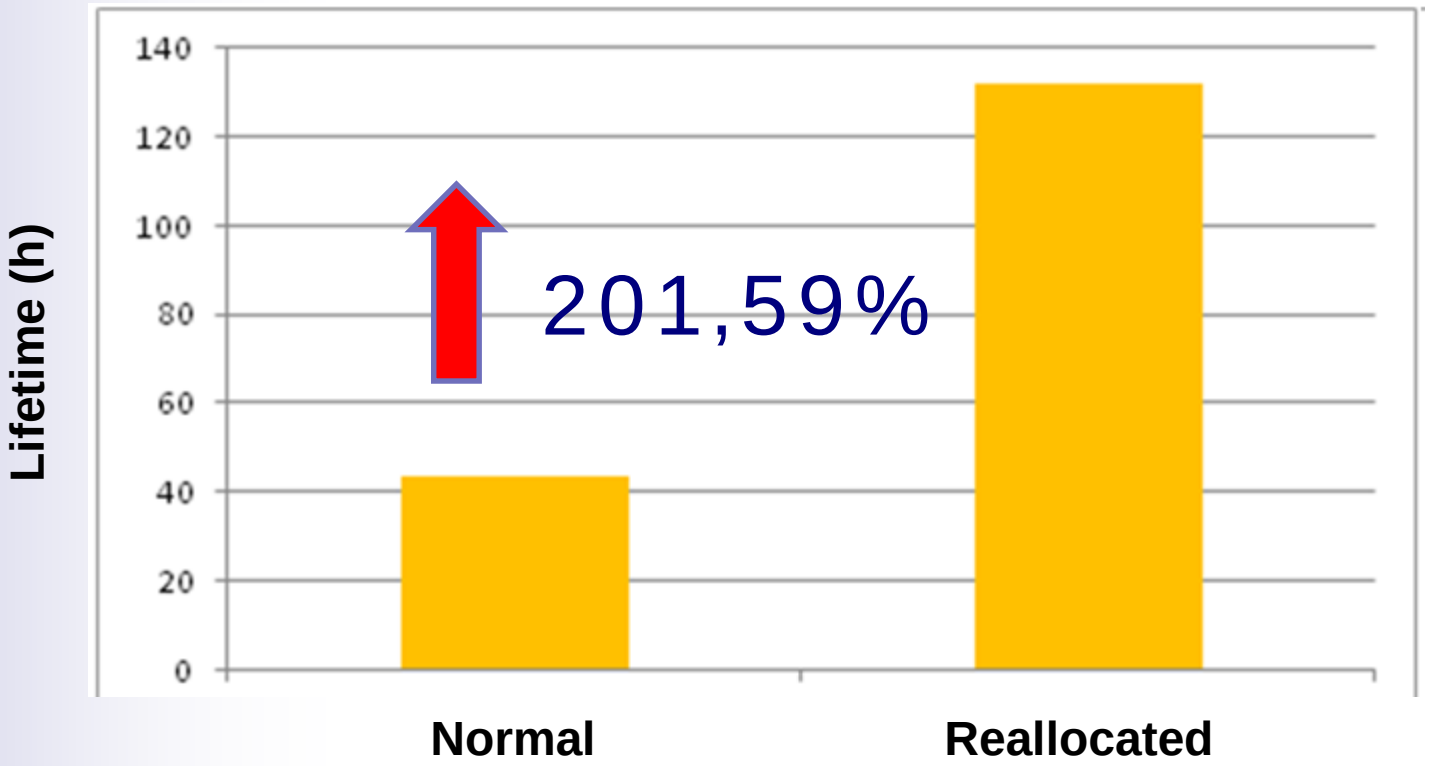

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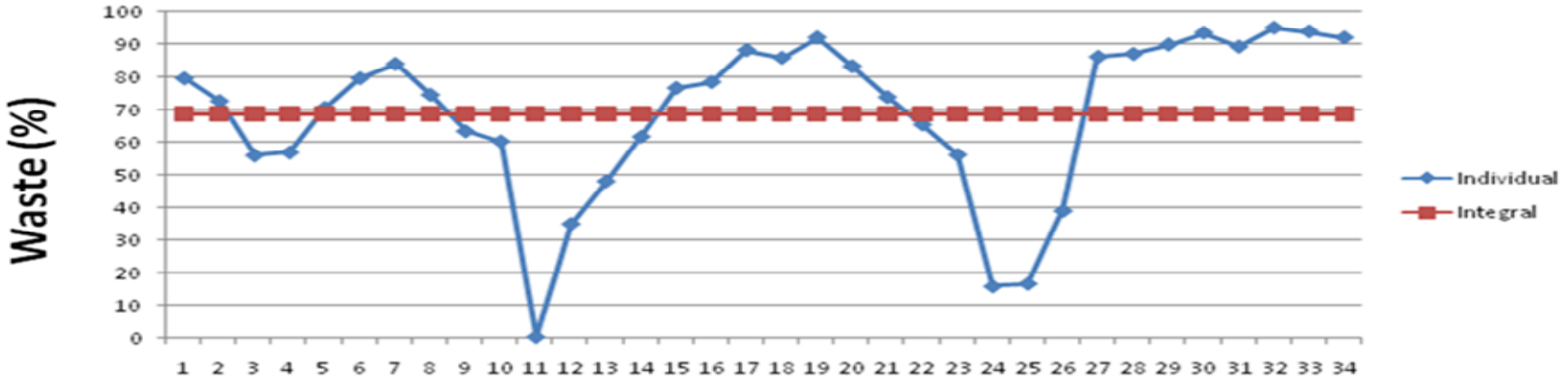
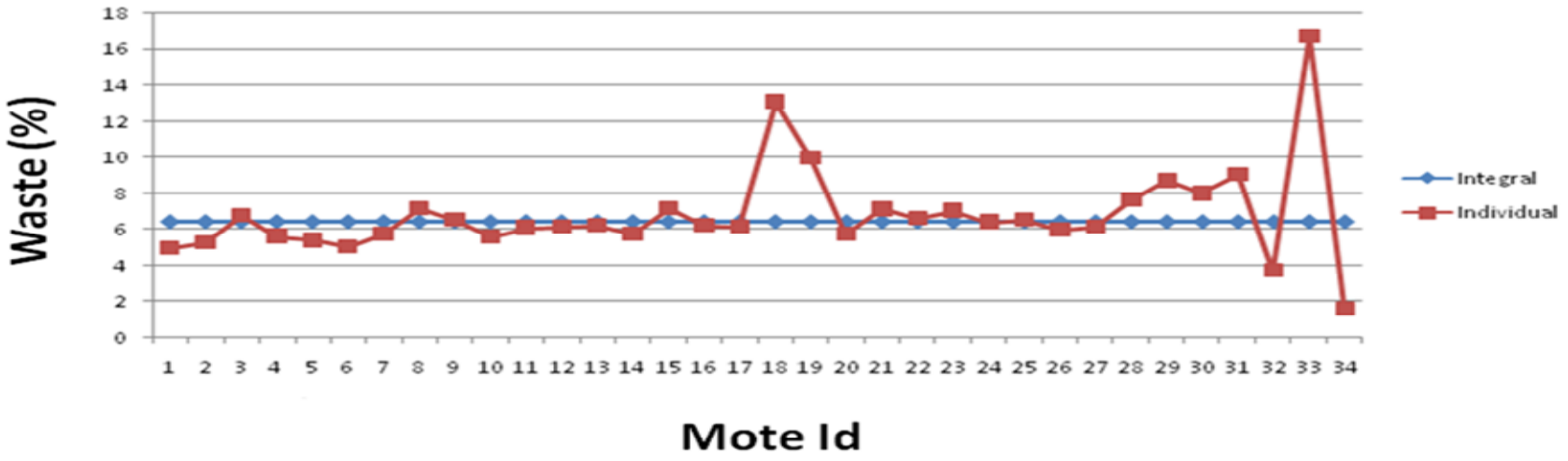
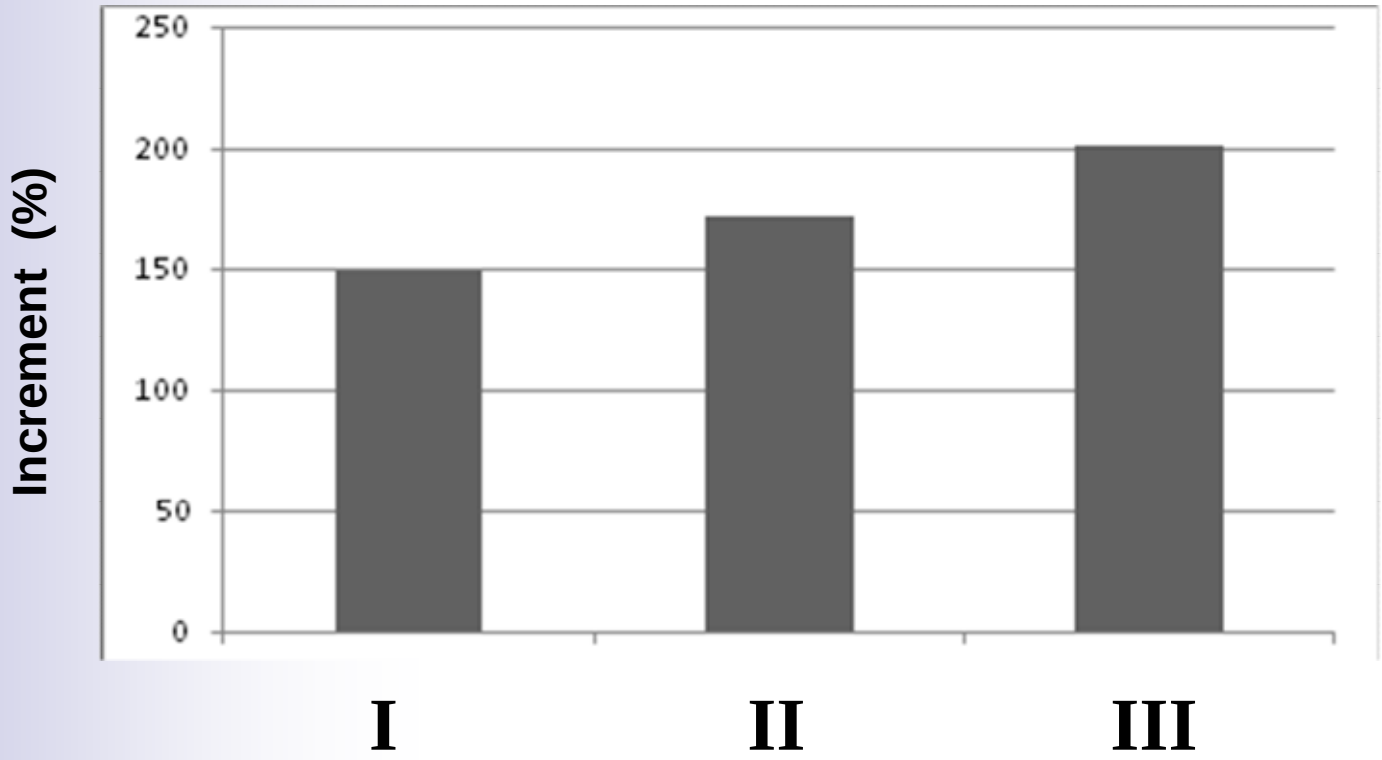
Validation

Energy Waste





Validation
Lifetime Increment



Conclusions

- **Very low estimation error**
  - **There was no case above 2%**
- **Long lifetime increment**
  - **Lifetime increment on all scenarios**
    - **Some with more than 200%**
- **Better energy use**
  - **Less energy waste**

OBRIGADO !

THANKS!

Ευχαριστίες!