Simulation of movements on construction sites.

An explorative study on the influence of 4D-BIM simulation of construction workers movements on construction sites to workhours and labour productivity.

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P5 Presentation

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I Introduction
II Theoretical background
III Implementing Dynamo
IV Simulations
V Behind Dynamo
VI Verification
VII Discussion & Conclusion

Introduction

- BIM
  - Not used to full potential
- Labour productivity
  - Relatively low

To what extent does the modelling of labour and movement of workforce into a 4D building information model have the ability to give insight into and indicate potentials to increase the labour productivity on construction sites.

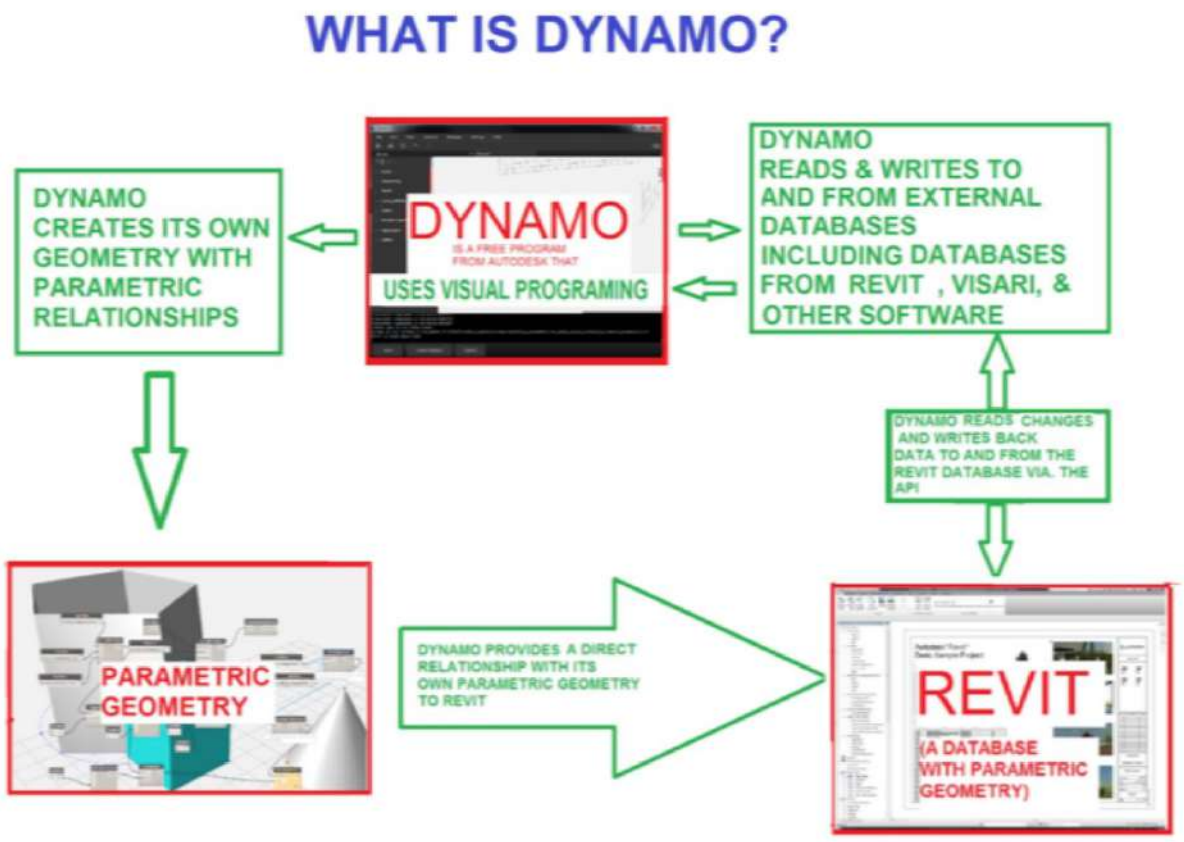
1) Which definition and aspects of productivity to be used?
2) Which data is needed from all parties to be integrated into a 4D Building Information Model?
3) How to accurately model the data into a 4D Building Information Model with labour and movements of workforce?
4) What are the possibilities of visualising the data into a 4D Building Information Model with labour and movements of workforce?
5) How to model interventions into a 4D Building Information Model with labour and movements of workforce?
6) What is the simulated change in productivity?
7) Can this simulated change in productivity be proved by the physical project?

II

Theoretical background

- Basis of 4D BIM
  - Relation between 3D and schedule
  - Benefits in
    - Visualisation
    - Multiple stakeholder impact
    - Site logistics
    - Coordinate trades
    - Compare schedules

Choice of Dynamo



- Path analysis
  - Actors
  - Starting point
  - Destination
  - Path
  - Means of transport
  - Activities

- Walk
  - Horizontal working
  - Vertical walking by stairs
  - Vertical walking by elevator
- Wait
- Work

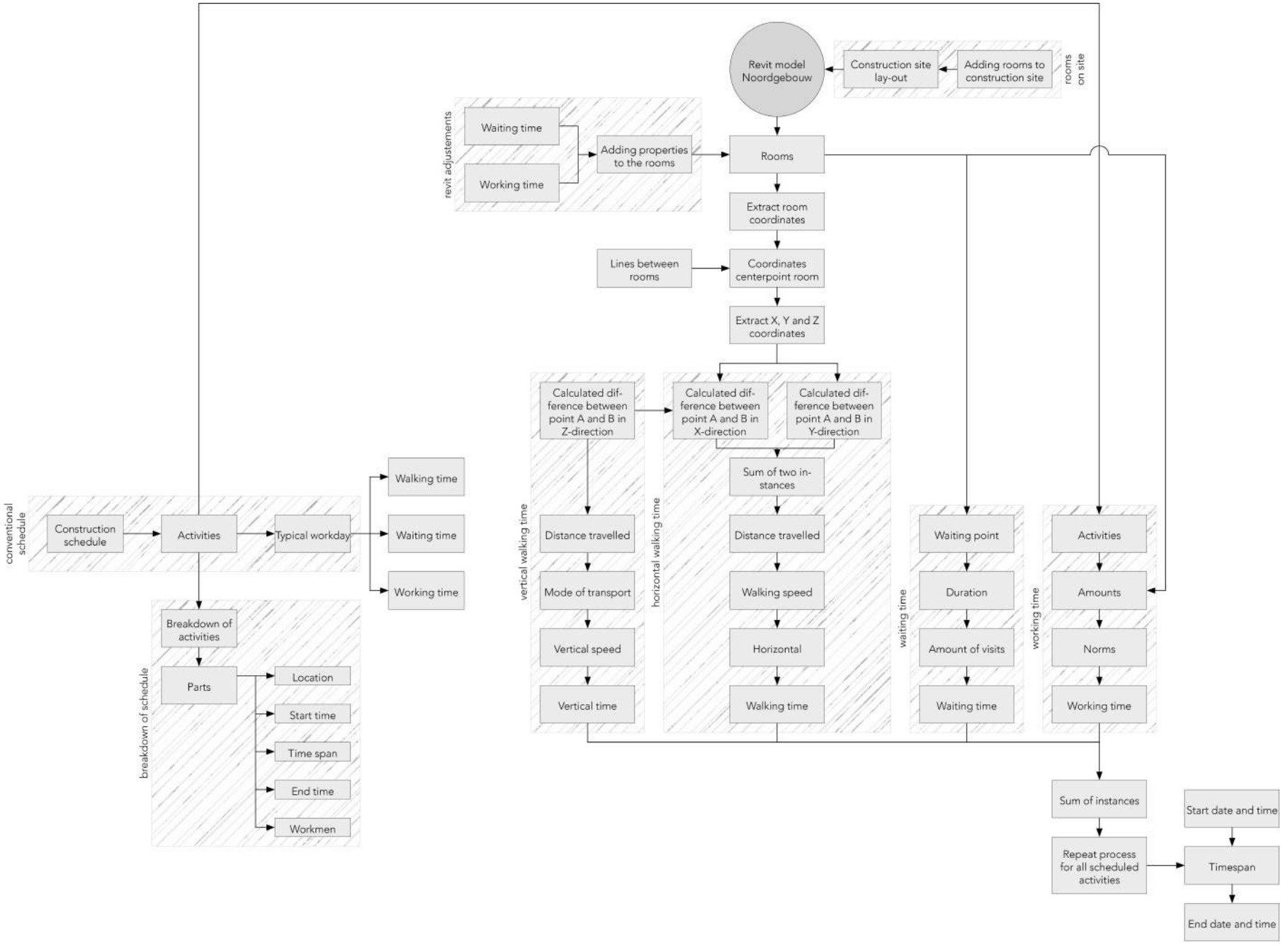
$$\text{labour productivity} = \frac{\text{input}}{\text{output}} = \frac{\text{total working time}}{\text{productive time}}$$

Productive (41,8%)	Productive (41,8%)	Productive (41,8%)
Unproductive (58,2%)	Muda 2 (30,6%)	Charging batteries (2,0%)
		Handeling/changing hand tools (3,1%)
		Transportation; moving equipment; walking; using vehicles (9,2%)
		Other waste; shovelling snow; removing tarps; streching cords (7,1%)
		Change of tasks; start-up and clean-up (9,2%)
	Muda 1 (27,6%)	Morning coffee break (4,1%)
		Locating tools/ladders (3,1%)
		Locating materials (4,1%)
		Restroom visits (4,1%)
		Waiting for instructions or materials (9,2%)
		Travel from and to lunch (3,1%)

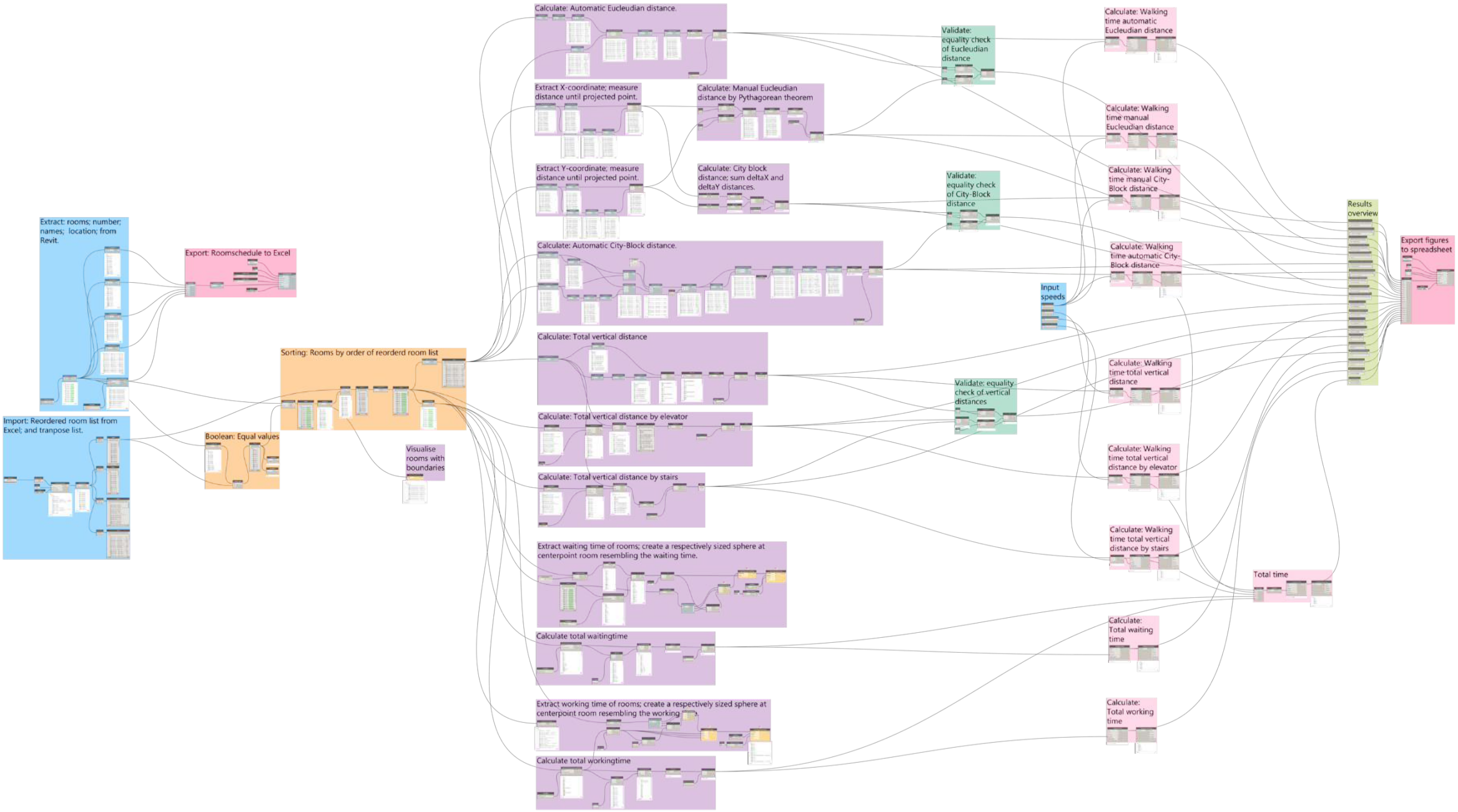
Working time 62,3 – 70,4%	Productive (47,0%)	Productive (41,8%)
	General instructions (4,2%)	Charging batteries (2,0%)
	Others (3,5%)	Handeling/changing hand tools (3,1%)
	Measuring (3,5%)	Other waste; shovelling snow; removing tarps; streching cords (7,1%)
	Cleaning (3,1%)	Change of tasks; start-up and clean-up (9,2%)
	Personal needs (0,6%)	Locating tools/ladders (3,1%)
	Rework (0,4%)	Locating materials (4,1%)
Walking time 12,3 - 19,7%	Transporting (13,7%)	Transportation; moving equipment; walking; using vehicles (9,2%)
	Traveling (6,0%)	Travel from and to lunch (3,1%)
Waiting time 17,4 – 17,8%	Waiting (9%)	Morning coffee break (4,1%)
	Idle time (6,8%)	Restroom visits (4,1%)
	Resting (2,0%)	Waiting for instructions or materials (9,2%)
	Alarcon (1997)	El Asmar (2012)

III

Implementing Dynamo


Revit model Noordgebouw
Construction site lay-out
Adding rooms to construction site
rooms on site
revit adjustements
Waiting time
Working time
Adding properties to the rooms
Rooms
Extract room coordinates
Lines between rooms
Coordinates centerpoint room
Extract X, Y and Z coordinates
Calculated difference between point A and B in Z-direction
Calculated difference between point A and B in X-direction
Calculated difference between point A and B in Y-direction
vertical walking time
Distance travelled
Mode of transport
Vertical speed
Vertical time
horizontal walking time
Sum of two instances
Distance travelled
Walking speed
Horizontal
Walking time
waiting time
Waiting point
Duration
Amount of visits
Waiting time
working time
Activities
Amounts
Norms
Working time
conventional schedule
Construction schedule
Activities
Typical workday
Walking time
Waiting time
Working time
breakdown of schedule
Breakdown of activities
Parts
Location
Start time
Time span
End time
Workmen
Sum of instances
Repeat process for all scheduled activities
Start date and time
Timespan
End date and time

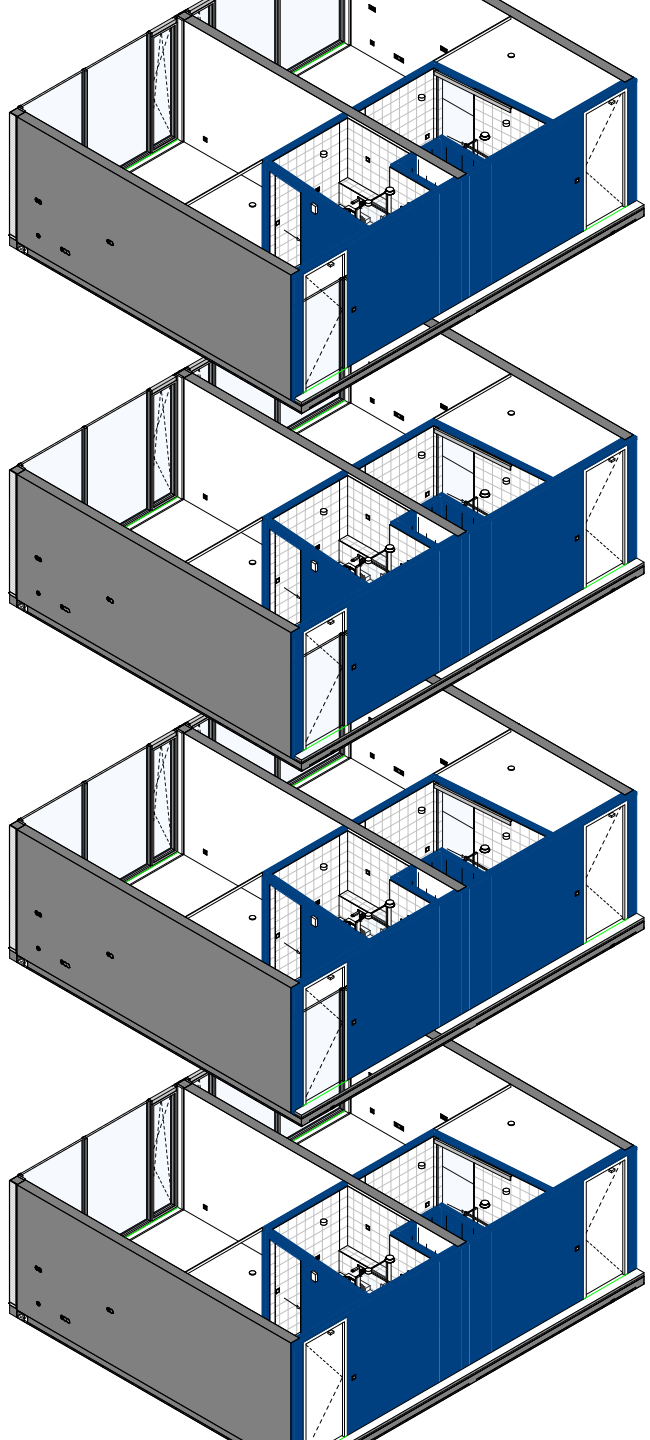
implementing dynamo – dynamo workspace



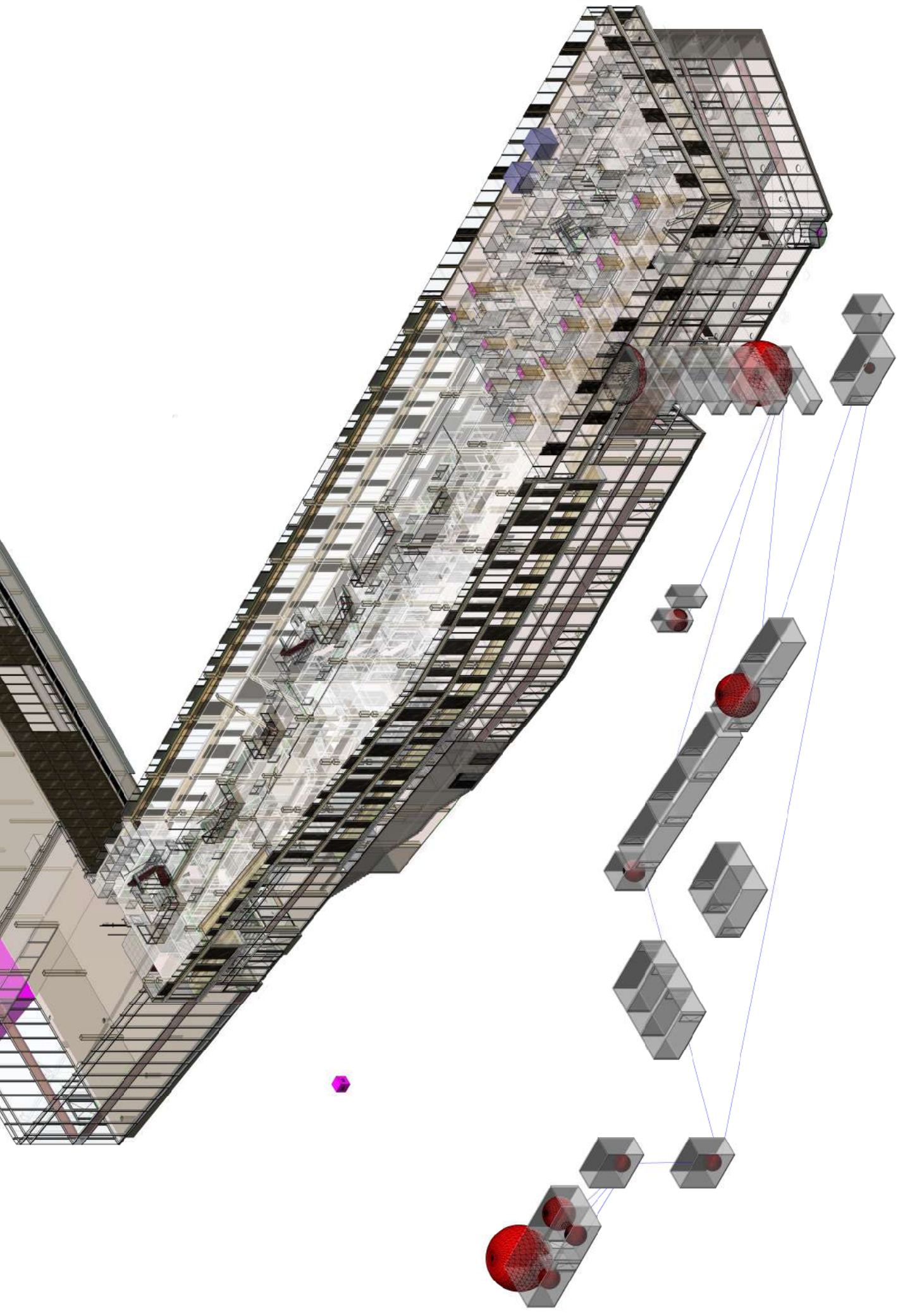
IV

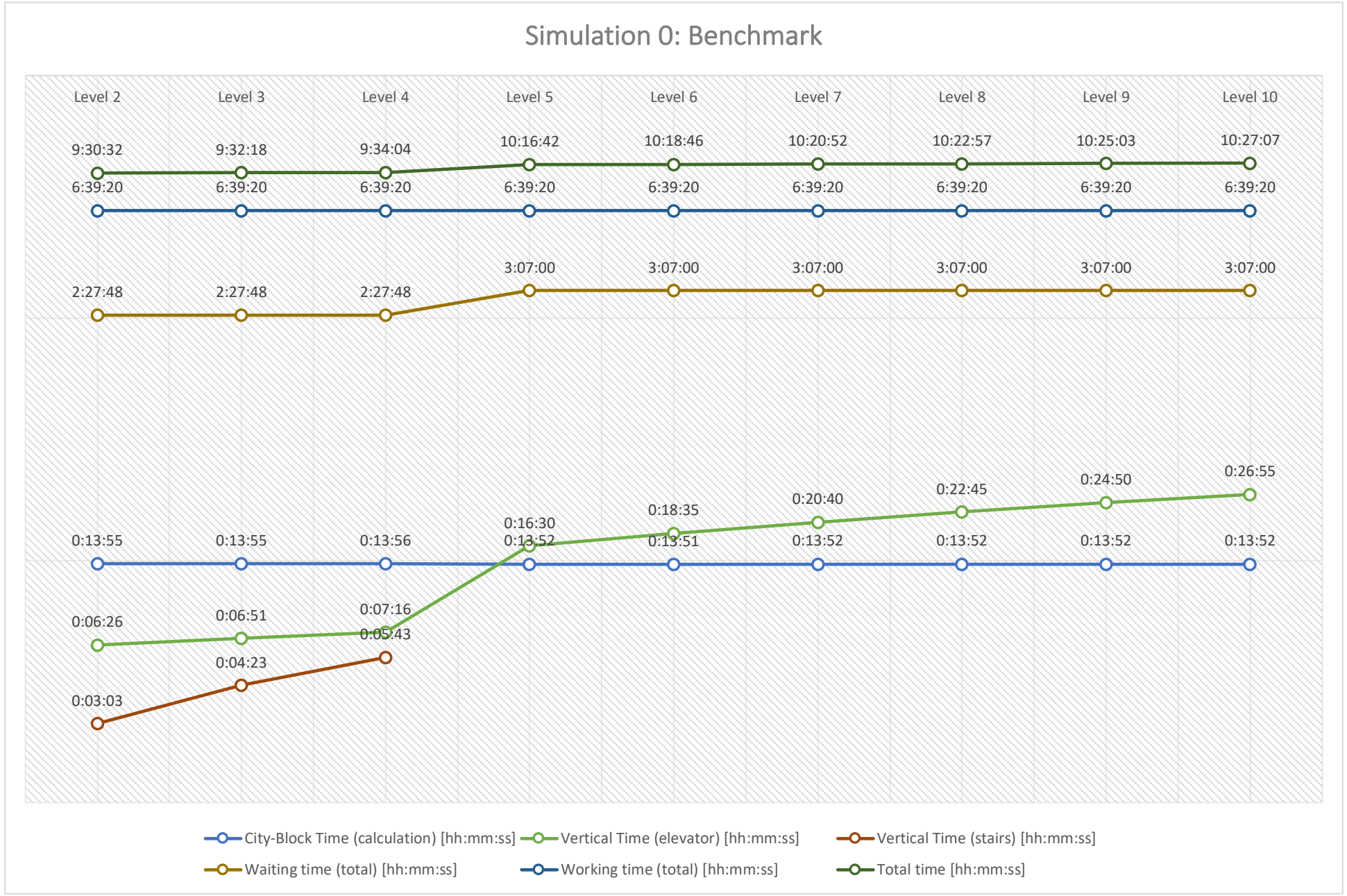
Simulations

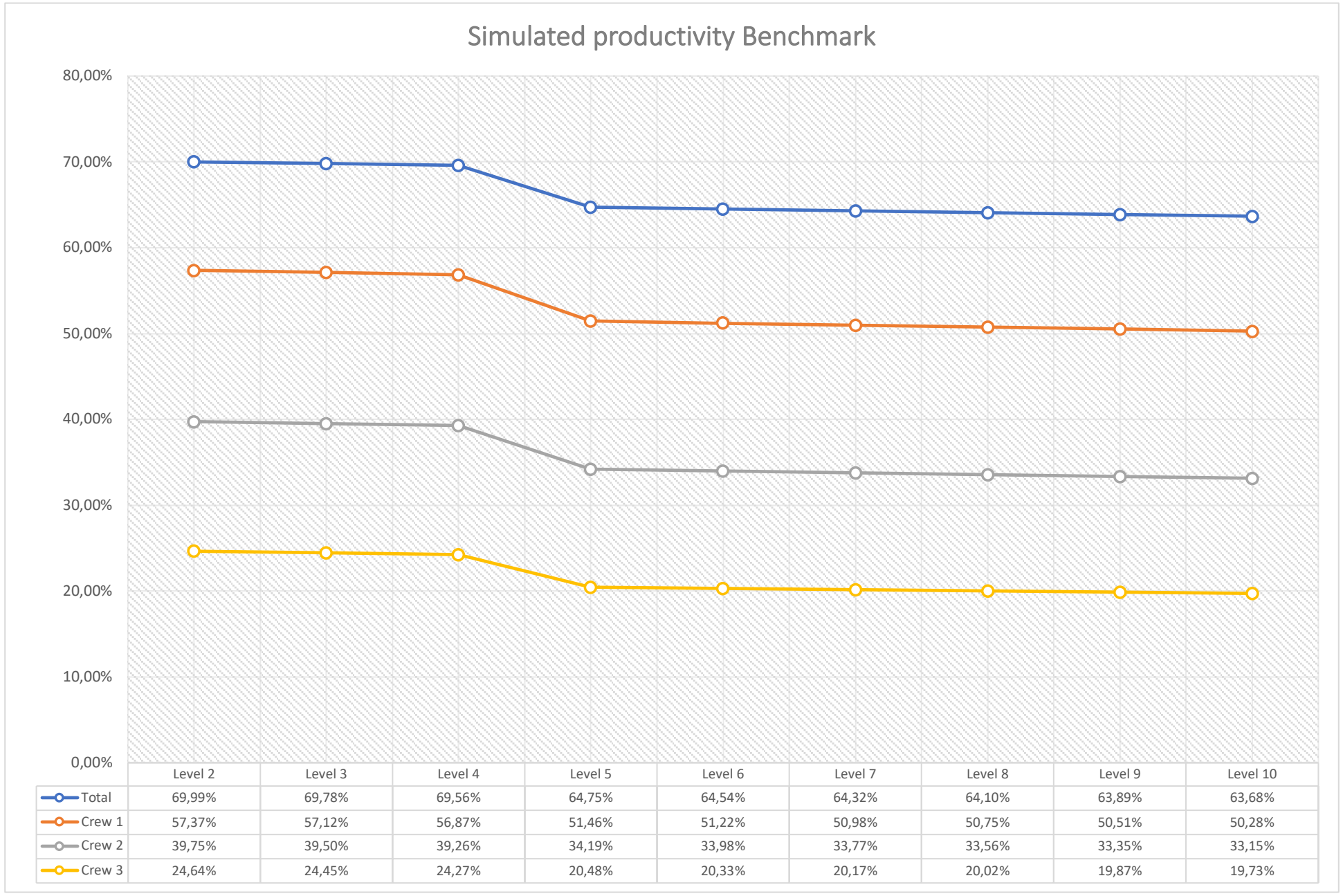
- Hotel rooms on all levels
- Working time
- Waiting time
- Walking time
- Typical workday



Simulation 0	Benchmark
Simulation 1	Intervention 1: Extra elevator
Simulation 2	Intervention 2: Toilets on levels
Simulation 3	Intervention 3: Elevator to corner
Simulation 4	Intervention 4: Elevator near work




Simulation 0: Benchmark
Level 2
Level 3
Level 4
Level 5
Level 6
Level 7
Level 8
Level 9
Level 10
9:30:32
9:32:18
9:34:04
10:16:42
10:18:46
10:20:52
10:22:57
10:25:03
10:27:07
6:39:20
6:39:20
6:39:20
6:39:20
6:39:20
6:39:20
6:39:20
6:39:20
6:39:20
2:27:48
2:27:48
2:27:48
3:07:00
3:07:00
3:07:00
3:07:00
3:07:00
3:07:00
0:13:55
0:13:55
0:13:56
0:16:30
0:13:52
0:18:35
0:13:51
0:20:40
0:13:52
0:22:45
0:13:52
0:24:50
0:13:52
0:26:55
0:13:52
0:06:26
0:06:51
0:07:16
0:05:43
0:04:23
0:03:03
City-Block Time (calculation) [hh:mm:ss]
Vertical Time (elevator) [hh:mm:ss]
Vertical Time (stairs) [hh:mm:ss]
Waiting time (total) [hh:mm:ss]
Working time (total) [hh:mm:ss]
Total time [hh:mm:ss]

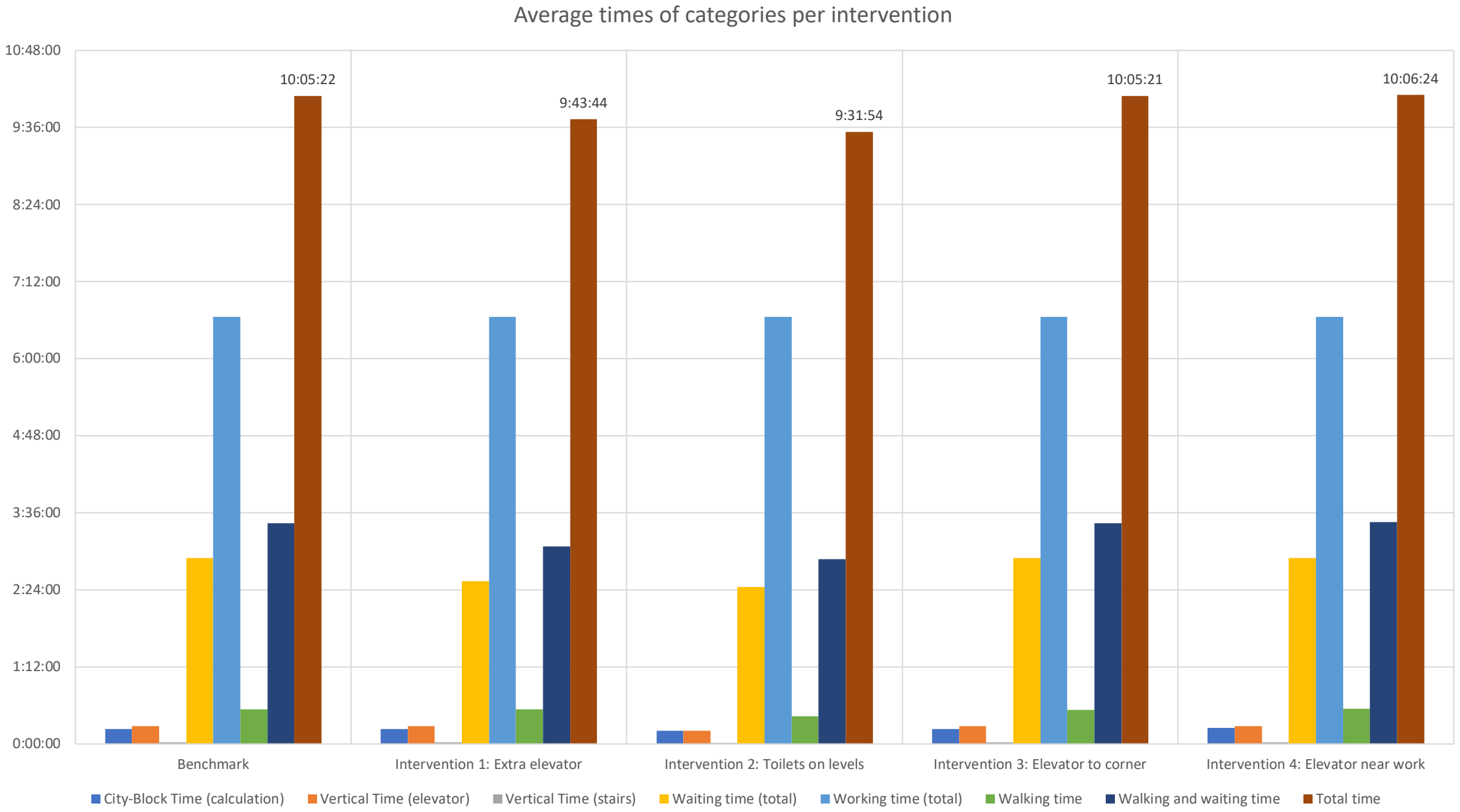


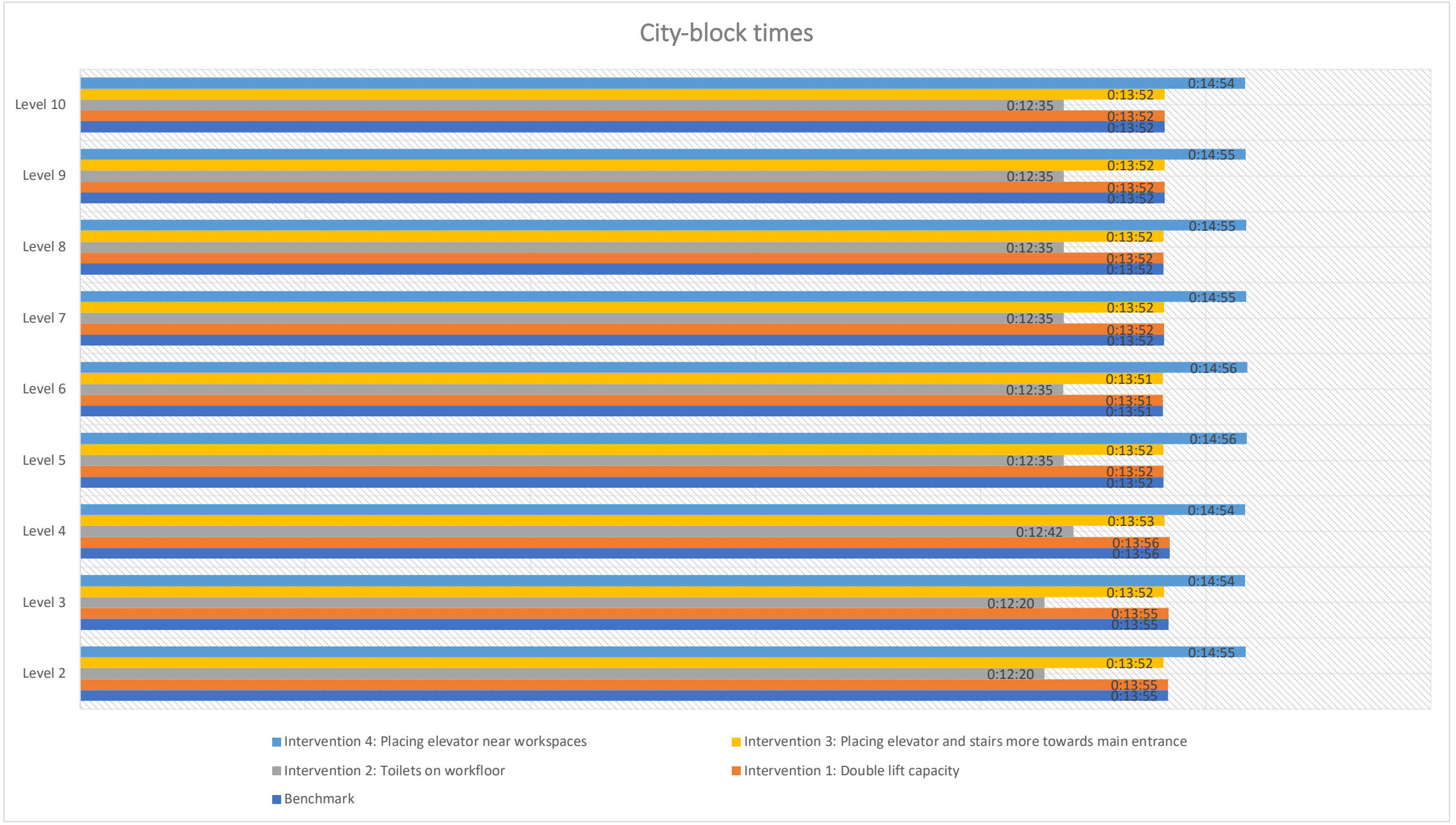
	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9	Level 10
Total	69,99%	69,78%	69,56%	64,75%	64,54%	64,32%	64,10%	63,89%	63,68%
Crew 1	57,37%	57,12%	56,87%	51,46%	51,22%	50,98%	50,75%	50,51%	50,28%
Crew 2	39,75%	39,50%	39,26%	34,19%	33,98%	33,77%	33,56%	33,35%	33,15%
Crew 3	24,64%	24,45%	24,27%	20,48%	20,33%	20,17%	20,02%	19,87%	19,73%

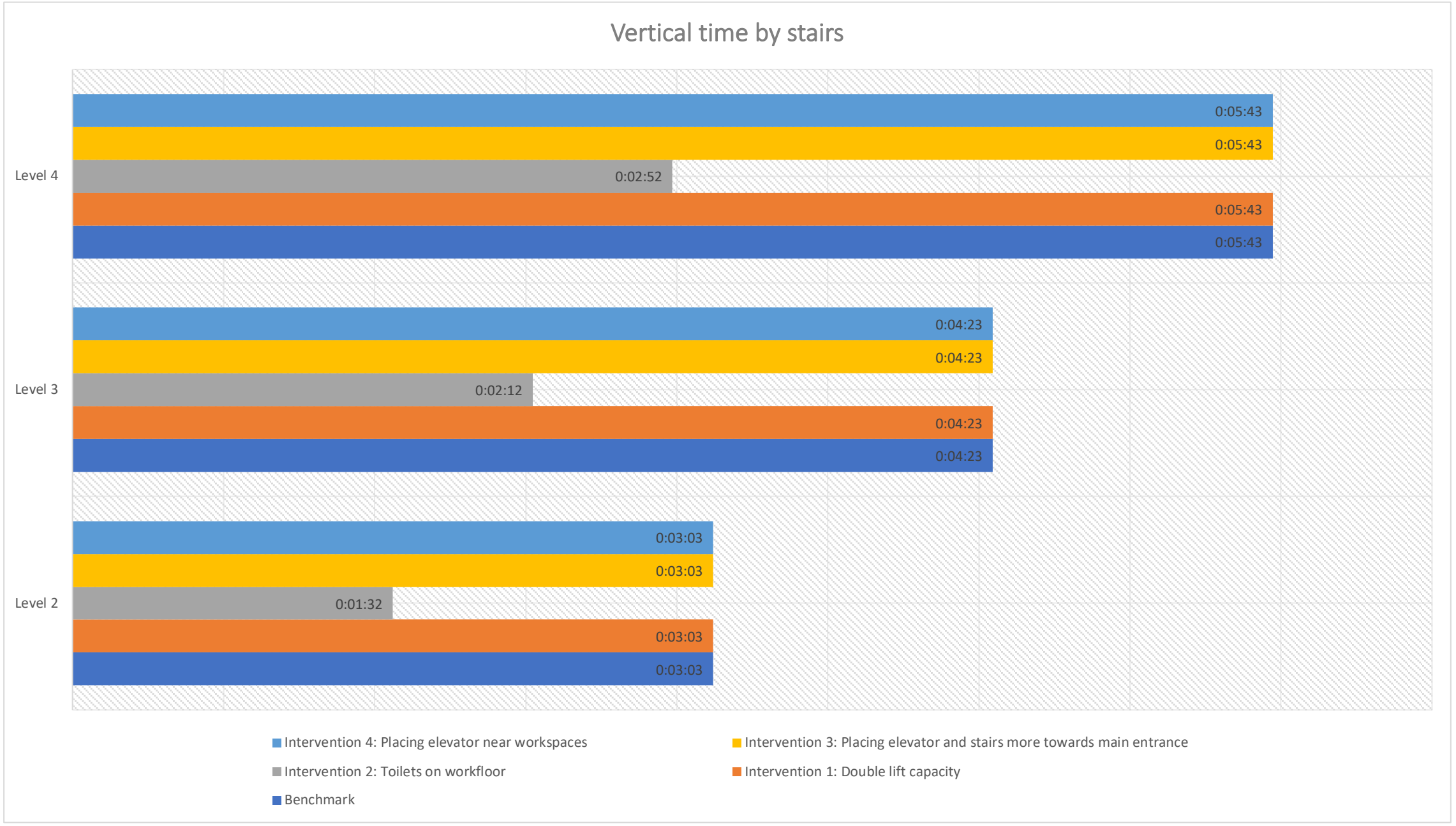
- Crews

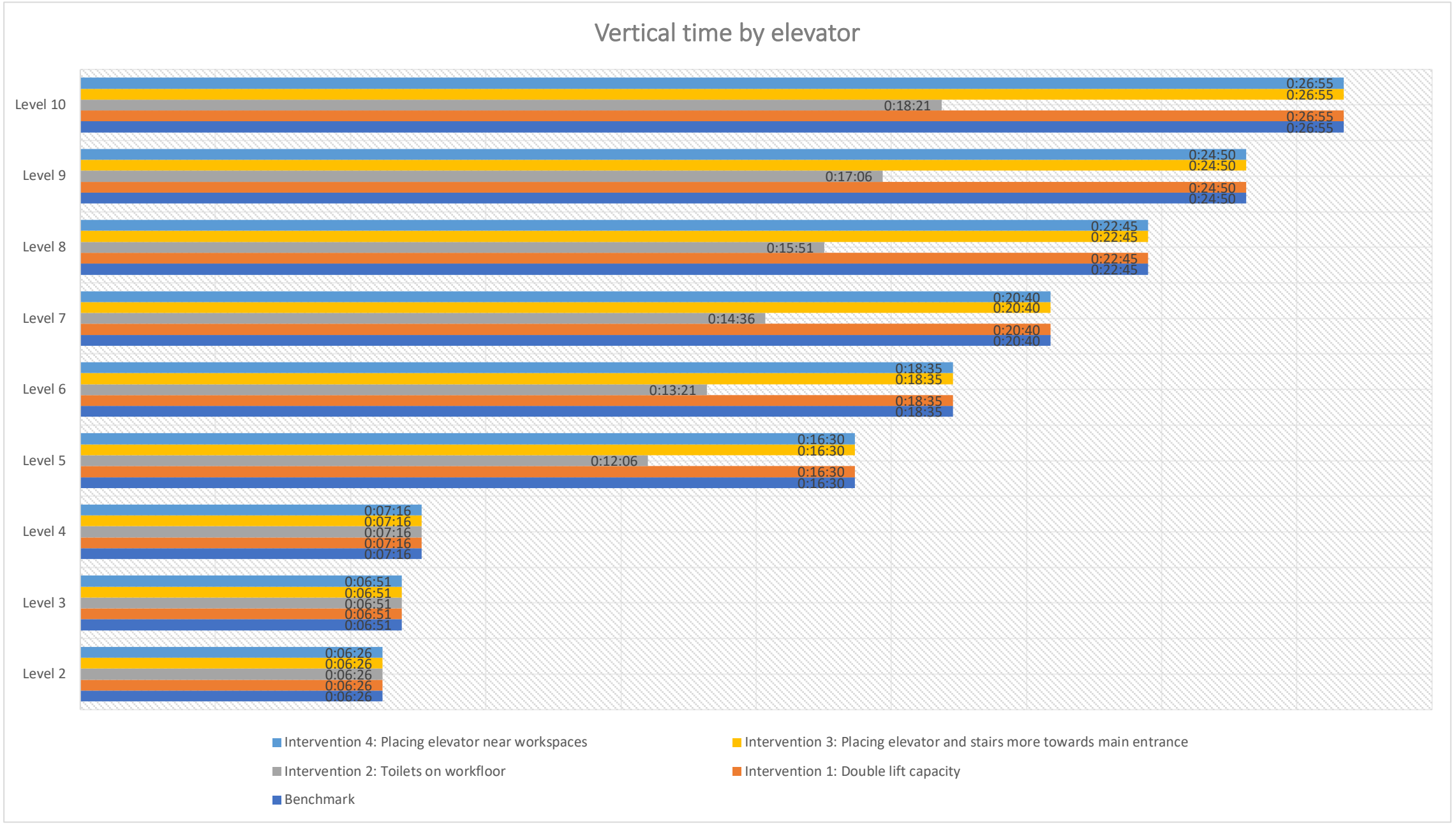
Total man-hour per room per step for all crews	
Studs	2.5211 man-hour per room
Insulation	0.2184 man-hour per room
Drywall	1.9079 man-hour per room
Finishing	0.9331 man-hour per room
Additional factors	1.0750 man-hour per room
Total	**6.656 man-hour per room**

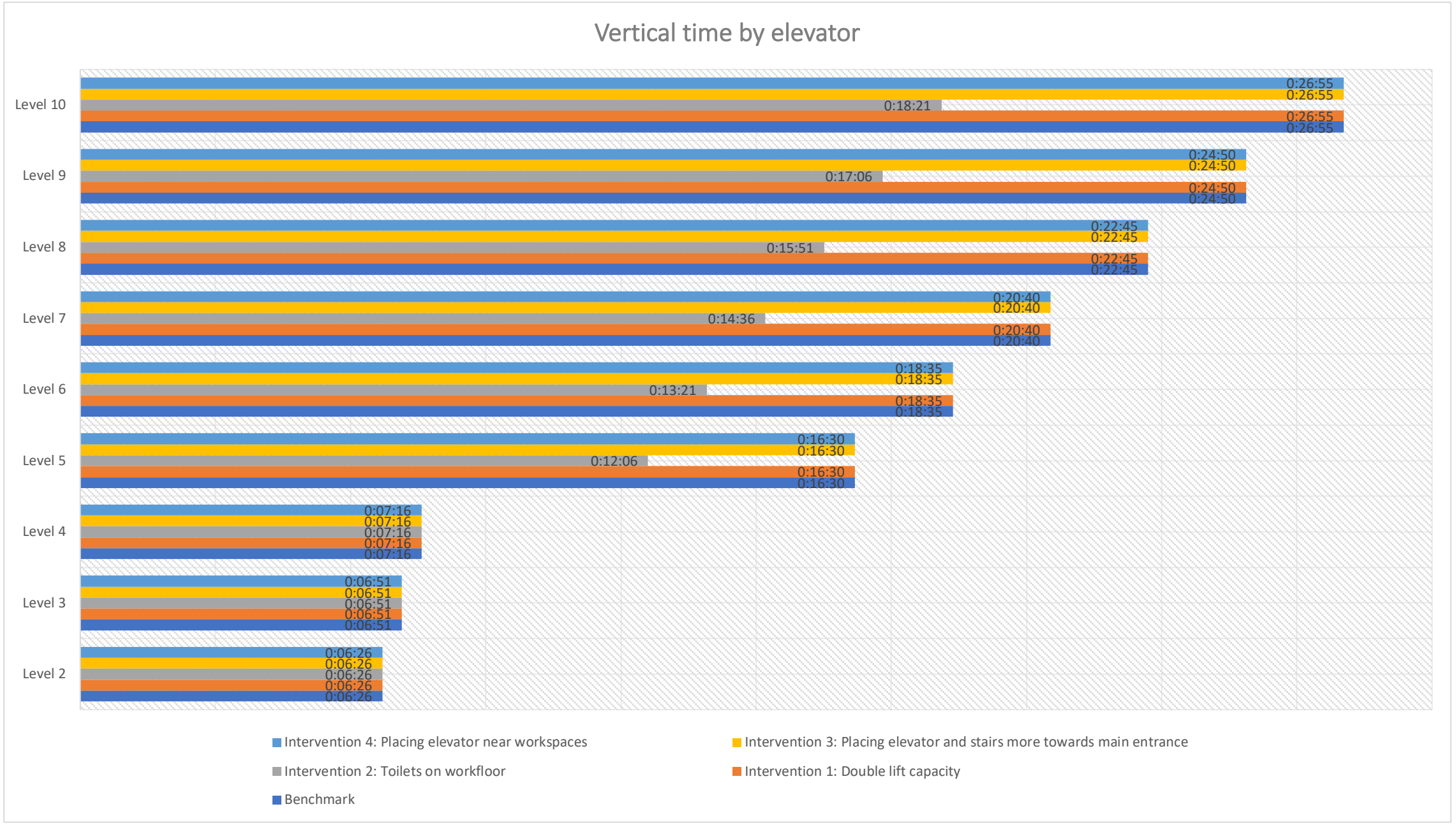
Total man-hour per room per crew		
Crew 1	Crew 2	Crew 3
Studs; backer board; doorframes; sheeting one side.	Insulation; receptacles; holes; sheeting second side.	Finishing.
3.840 man-hour per room	**1.882 man-hour per room**	**0.933 man-hour per room**

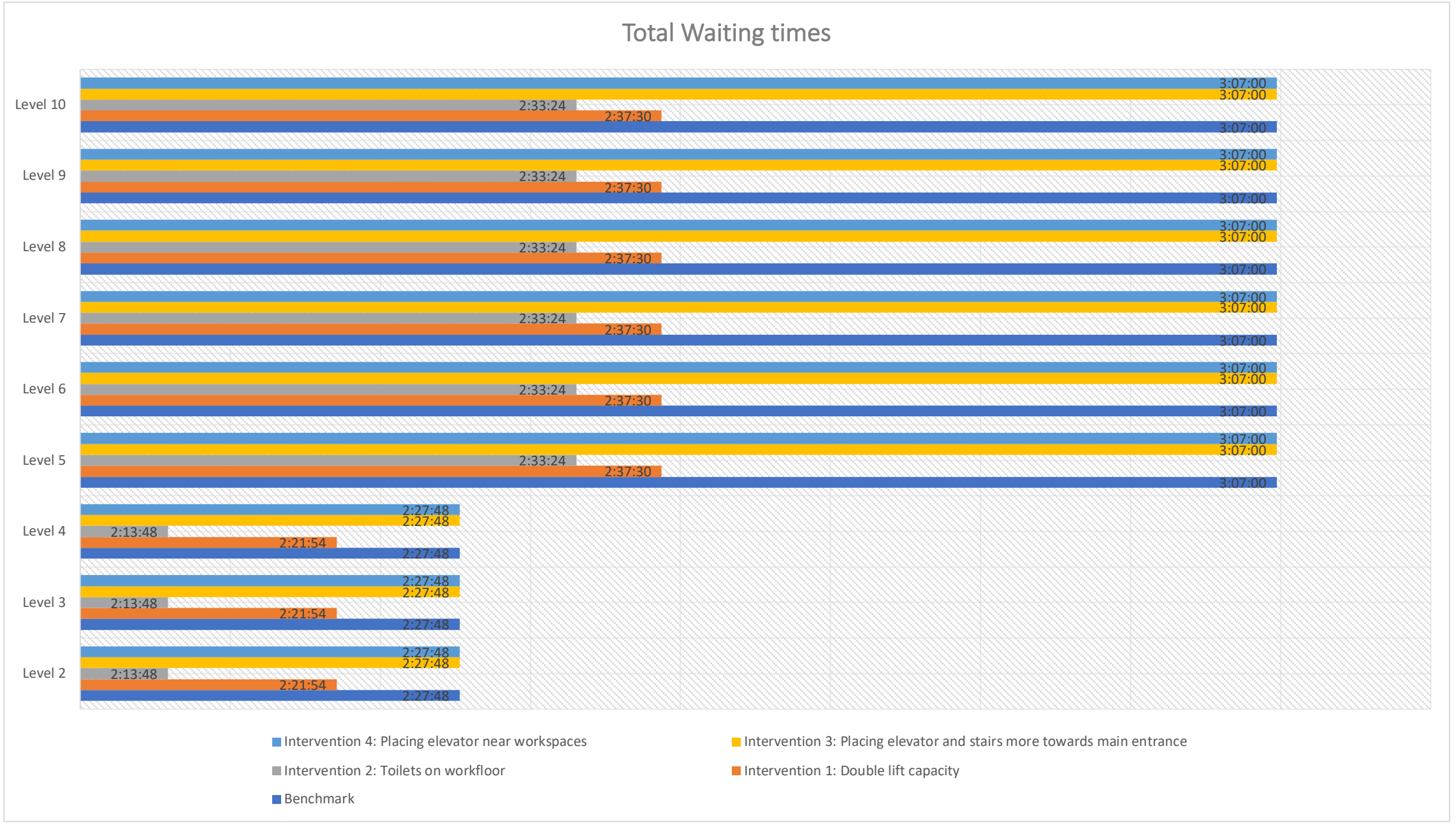

Average times of categories per intervention
10:48:00
9:36:00
8:24:00
7:12:00
6:00:00
4:48:00
3:36:00
2:24:00
1:12:00
0:00:00
10:05:22
9:43:44
9:31:54
10:05:21
10:06:24
Benchmark
Intervention 1: Extra elevator
Intervention 2: Toilets on levels
Intervention 3: Elevator to corner
Intervention 4: Elevator near work
City-Block Time (calculation)
Vertical Time (elevator)
Vertical Time (stairs)
Waiting time (total)
Working time (total)
Walking time
Walking and waiting time
Total time

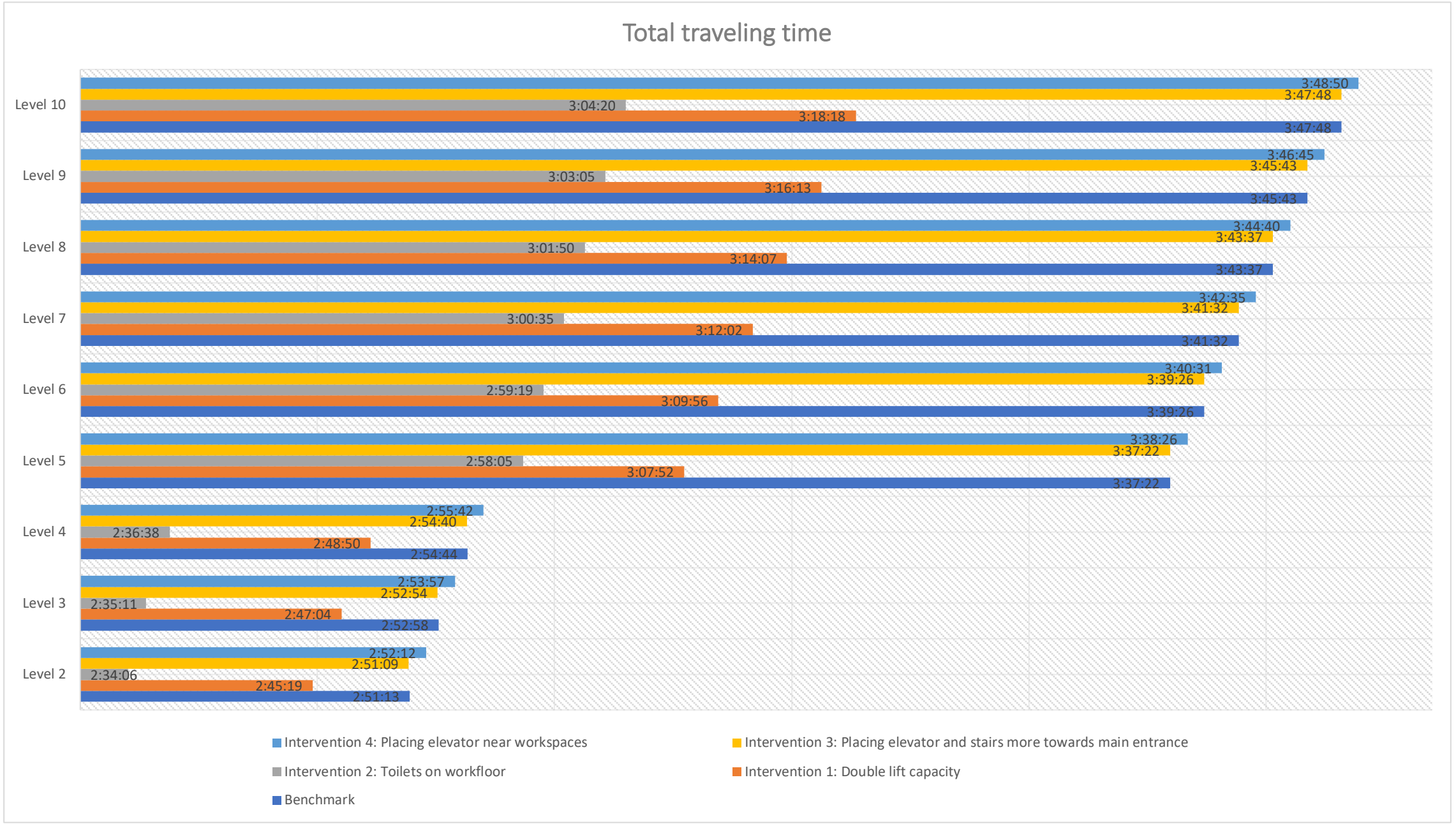

City-block times
Level 10
0:14:54
0:13:52
0:12:35
0:13:52
0:13:52
Level 9
0:14:55
0:13:52
0:12:35
0:13:52
0:13:52
Level 8
0:14:55
0:13:52
0:12:35
0:13:52
0:13:52
Level 7
0:14:55
0:13:52
0:12:35
0:13:52
0:13:52
Level 6
0:14:56
0:13:51
0:12:35
0:13:51
0:13:51
Level 5
0:14:56
0:13:52
0:12:35
0:13:52
0:13:52
Level 4
0:14:54
0:13:53
0:12:42
0:13:56
0:13:56
Level 3
0:14:54
0:13:52
0:12:20
0:13:55
0:13:55
Level 2
0:14:55
0:13:52
0:12:20
0:13:55
0:13:55
Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark

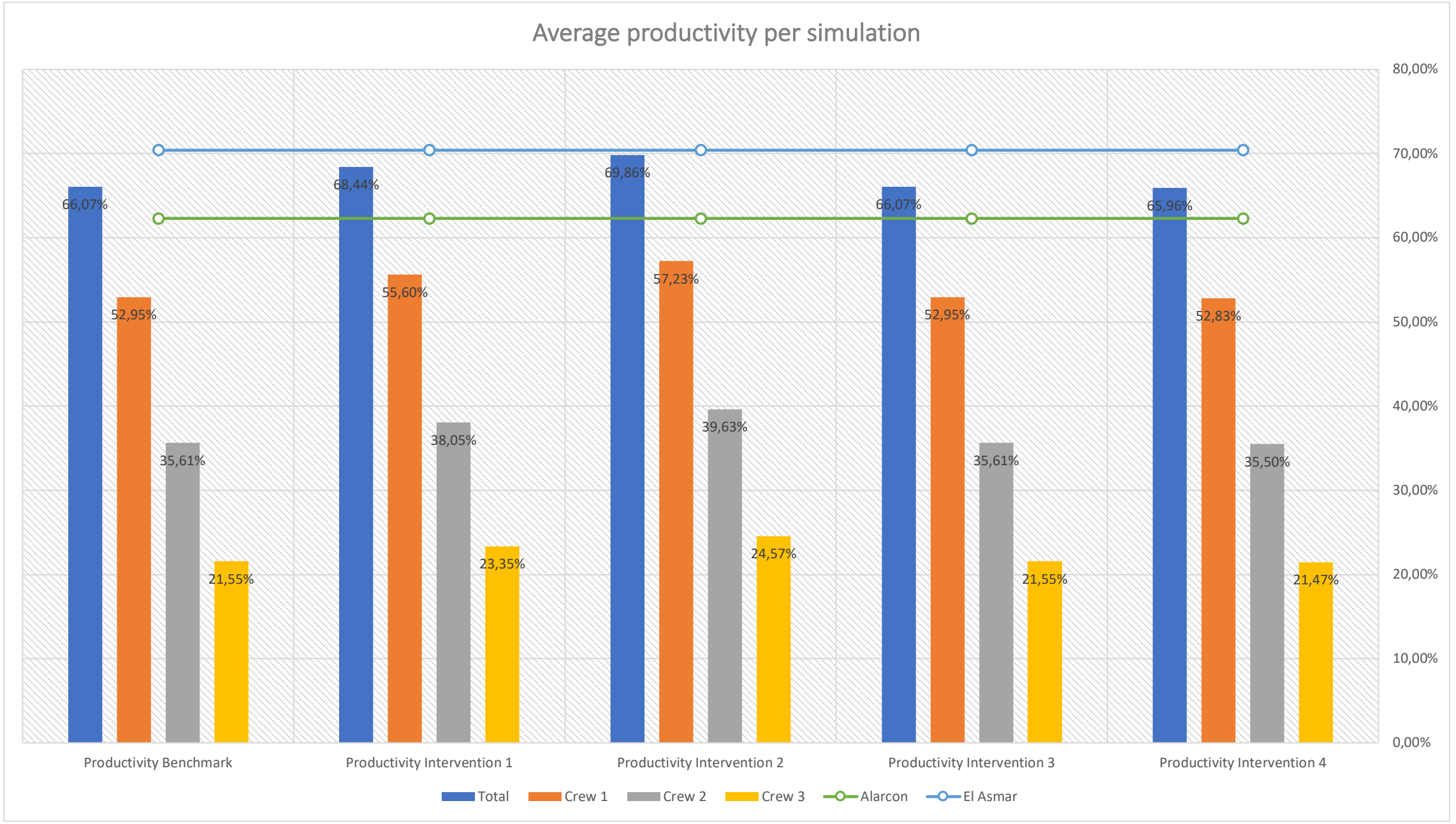

Vertical time by stairs
Level 4
0:05:43
0:05:43
0:02:52
0:05:43
0:05:43
Level 3
0:04:23
0:04:23
0:02:12
0:04:23
0:04:23
Level 2
0:03:03
0:03:03
0:01:32
0:03:03
0:03:03
Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark

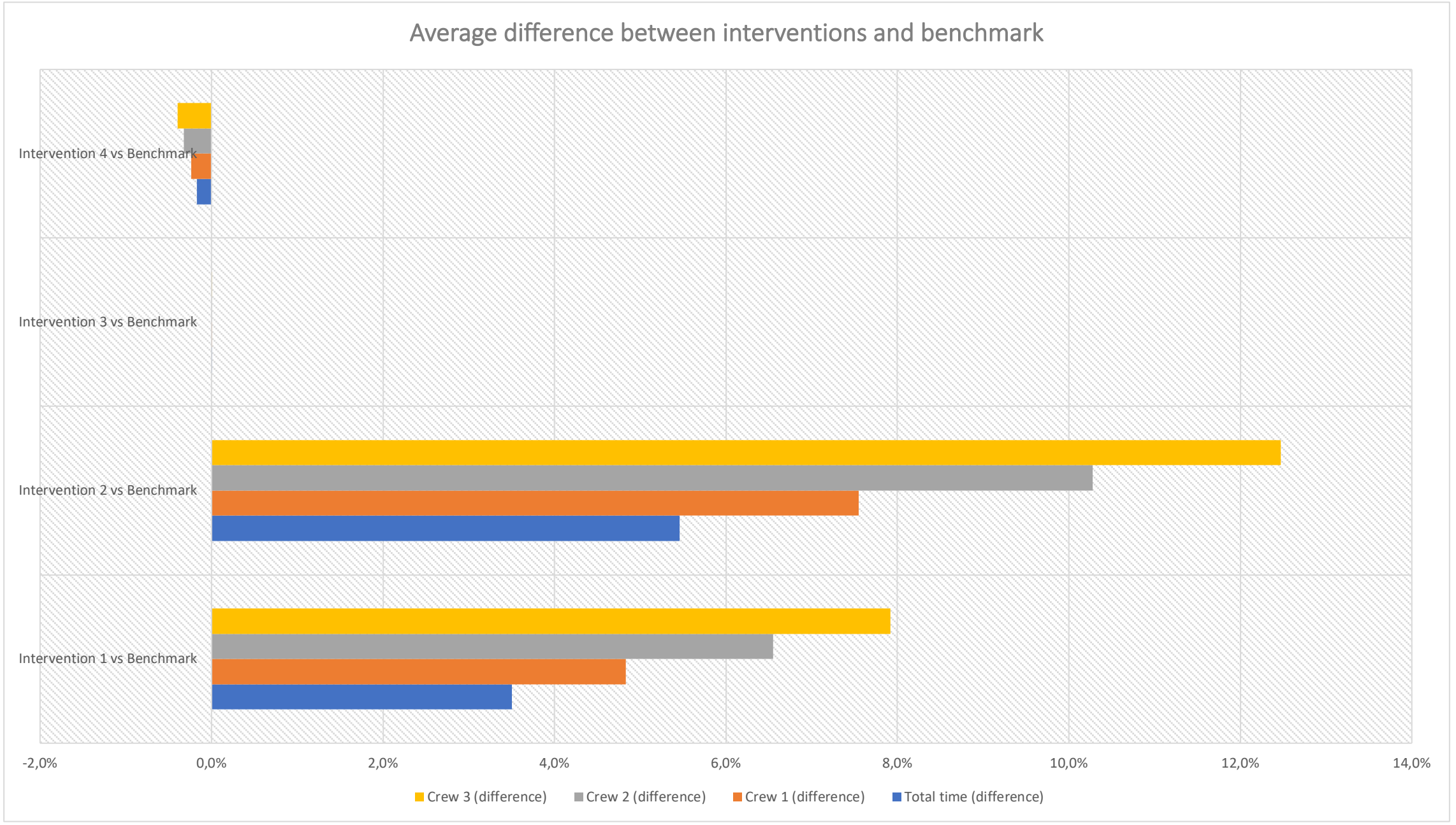

Vertical time by elevator
Level 10
0:26:55
0:26:55
0:18:21
0:26:55
0:26:55
Level 9
0:24:50
0:24:50
0:17:06
0:24:50
0:24:50
Level 8
0:22:45
0:22:45
0:15:51
0:22:45
0:22:45
Level 7
0:20:40
0:20:40
0:14:36
0:20:40
0:20:40
Level 6
0:18:35
0:18:35
0:13:21
0:18:35
0:18:35
Level 5
0:16:30
0:16:30
0:12:06
0:16:30
0:16:30
Level 4
0:07:16
0:07:16
0:07:16
0:07:16
0:07:16
Level 3
0:06:51
0:06:51
0:06:51
0:06:51
0:06:51
Level 2
0:06:26
0:06:26
0:06:26
0:06:26
0:06:26
Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark


Vertical time by elevator
Level 10
0:26:55
0:26:55
0:18:21
0:26:55
0:26:55
Level 9
0:24:50
0:24:50
0:17:06
0:24:50
0:24:50
Level 8
0:22:45
0:22:45
0:15:51
0:22:45
0:22:45
Level 7
0:20:40
0:20:40
0:14:36
0:20:40
0:20:40
Level 6
0:18:35
0:18:35
0:13:21
0:18:35
0:18:35
Level 5
0:16:30
0:16:30
0:12:06
0:16:30
0:16:30
Level 4
0:07:16
0:07:16
0:07:16
0:07:16
0:07:16
Level 3
0:06:51
0:06:51
0:06:51
0:06:51
0:06:51
Level 2
0:06:26
0:06:26
0:06:26
0:06:26
0:06:26
Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark


Total Waiting times
Level 10
Level 9
Level 8
Level 7
Level 6
Level 5
Level 4
Level 3
Level 2
3:07:00
2:33:24
2:37:30
2:27:48
2:13:48
2:21:54
Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark


Total traveling time
Level 10
3:48:50
3:47:48
3:04:20
3:18:18
3:47:48
Level 9
3:46:45
3:45:43
3:03:05
3:16:13
3:45:43
Level 8
3:44:40
3:43:37
3:01:50
3:14:07
3:43:37
Level 7
3:42:35
3:41:32
3:00:35
3:12:02
3:41:32
Level 6
3:40:31
3:39:26
2:59:19
3:09:56
3:39:26
Level 5
3:38:26
3:37:22
2:58:05
3:07:52
3:37:22
Level 4
2:55:42
2:54:40
2:36:38
2:48:50
2:54:44
Level 3
2:53:57
2:52:54
2:35:11
2:47:04
2:52:58
Level 2
2:52:12
2:51:09
2:34:06
2:45:19
2:51:13
Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark


Average productivity per simulation
80,00%
70,00%
60,00%
50,00%
40,00%
30,00%
20,00%
10,00%
0,00%
66,07%
52,95%
35,61%
21,55%
68,44%
55,60%
38,05%
23,35%
69,86%
57,23%
39,63%
24,57%
66,07%
52,95%
35,61%
21,55%
65,96%
52,83%
35,50%
21,47%
Productivity Benchmark
Productivity Intervention 1
Productivity Intervention 2
Productivity Intervention 3
Productivity Intervention 4
Total
Crew 1
Crew 2
Crew 3
Alarcon
El Asmar


Average difference between interventions and benchmark
Intervention 4 vs Benchmark
Intervention 3 vs Benchmark
Intervention 2 vs Benchmark
Intervention 1 vs Benchmark
-2,0%
0,0%
2,0%
4,0%
6,0%
8,0%
10,0%
12,0%
14,0%
Crew 3 (difference)
Crew 2 (difference)
Crew 1 (difference)
Total time (difference)

Behind Dynamo

- Preparing Revit
  - Rooms
  - Site lay-out
  - Working and waiting time
- Typical workday
  - Interview with dry-wall contractor
- Walking speed
  - Horizontal
  - Vertical by stair
- Waiting time
  - Waiting time of elevator
  - Vertical by elevator
- Working time
  - Norms

VI

Verification

verification – expert panel

- Two sessions
  - BIM-employees of Dura Vermeer
  - Construction team of Dura Vermeer and BIM-consultant

- Problem in decision making
- Introduction of simulations in construction process
- Different building phases
- Dependencies on site and with schedule
- Project size and shape
- Waiting times
- Difference in construction workers

verification - productivity

- Traditional projects
- Work productive for entire day

VII

Discussion & Conclusion

- Discussion
  - Model
    - Typical workday
    - Elevator
    - Waiting time
    - Walking lines
    - Necessity of working time

- Discussion
  - Productivity
    - Ratio between walking, waiting and working
    - Smart construction logistics
    - Different crews

1. Which definition and aspects of productivity to be used?

$$\text{labour productivity} = \frac{\text{input}}{\text{output}} = \frac{\text{total working time}}{\text{productive time}}$$

	Alarcon (1997)	El Asmar (2012)
Working time	62,3%	70,4%
Walking time	19,7%	12,3%
Waiting time	17,8%	17,4%

2. Which data is needed from all parties to be integrated into a 4D Building Information Model?

- Construction site lay-out
- Walking
- Waiting
- Working
- Typical workday

3. How to accurately model the data into a 4D Building Information Model with labour and movements of workforce?

- Walking
- Waiting
- Working

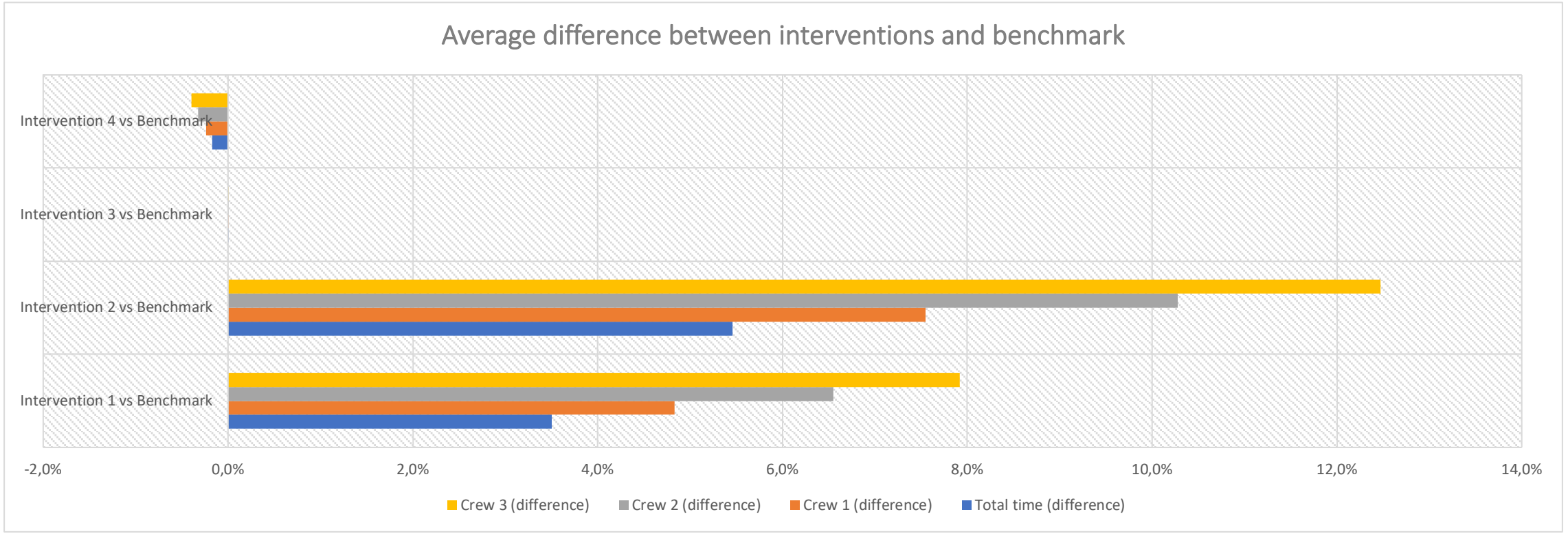
4. What are the possibilities of visualizing the data into a 4D Building Information Model with labour and movements of workforce?

- Walking lines
- Waiting and Working times

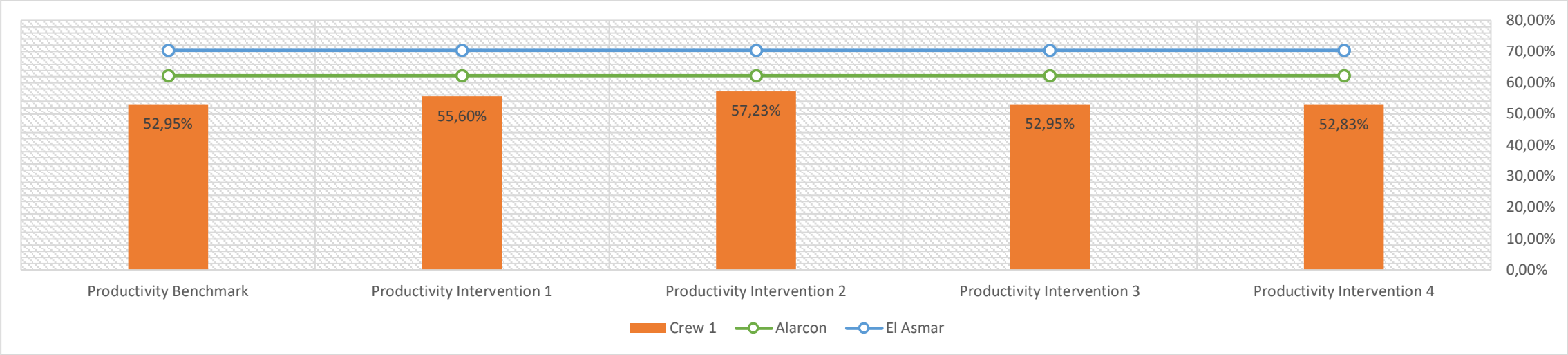
5. How to model interventions into a 4D Building Information Model with labour and movements of workforce?

- Waiting times
- Typical workday
- Site lay-out

6. What is the simulated change in productivity?



7. Can this simulated change in productivity be proved by the physical project?



To what extent does the modelling of labour and movement of workforce into a 4D building information model have the ability to give insight into and indicate potentials to increase the labour productivity on construction sites.

- Quite a big extent
- First step

- Ratio working, walking, waiting
- Multiple actors
- Building shape
- Order of construction
- Refinement of model
  - Visualisation of walking line and waiting times
  - Horizontal walking lines
  - Waiting time elevator


einde.