

CLINICAL LABORATORY OPTIMIZATION

Ph.D. Dissertation Defense

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17 December 2018

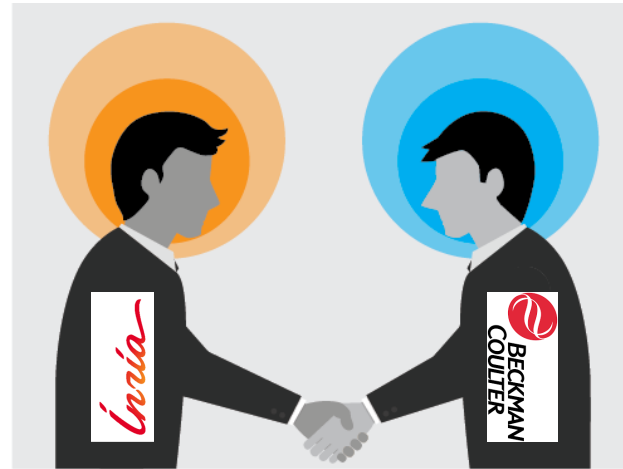




PROJECT CONTEXT

● Research Collaboration

The Most comprehensive research study done on clinical laboratory (CL) optimization



Three years



Teamwork



Weekly meetings

● Main Objectives

- ❖ Develop a **decision support tool** to ease decision making of large laboratory organization design
- ❖ Develop a **customized simulation tool** for clinical laboratory analysis, evaluation and decision making



PROJECT MOTIVATION & SIGNIFICANCE

- Cost and reimbursement constraints drive **concentration of laboratories**
 - ▣ Larger organizations are more **complex** to manage
- Healthcare **demand is growing**
 - ▣ Bring more works to laboratories
- Comprehensive mastering of laboratories organization becomes too complex to be **handled manually**
- Manageable simple solutions adopted could be **distant from efficient solutions**
- An **essential need** for an efficient **decision support tool** is highly appreciated



PROJECT CHALLENGES

- **Lack of comprehensive reference** on clinical laboratory organization

Sources of information	Project main activities			
	CL understanding	CL components understanding	Problem identification & description	Modeling & validation
Expert knowledge	×	×	×	×
Laboratory visit	×	×	×	
'LabSim' simulation tool		×		×
Machine manufacturer website		×		×
Laboratory database				×

- **Poor literature** on clinical laboratory optimization

▣ Mostly **simulation studies** for a **specific problem** on a **specific case**



CLINICAL LABORATORY

Definition

Clinical analysis laboratory is an organization gathering **human** and **machinery resources** to analyze human fluid samples such as blood.

Collection site and Examination site



With standalone sorter

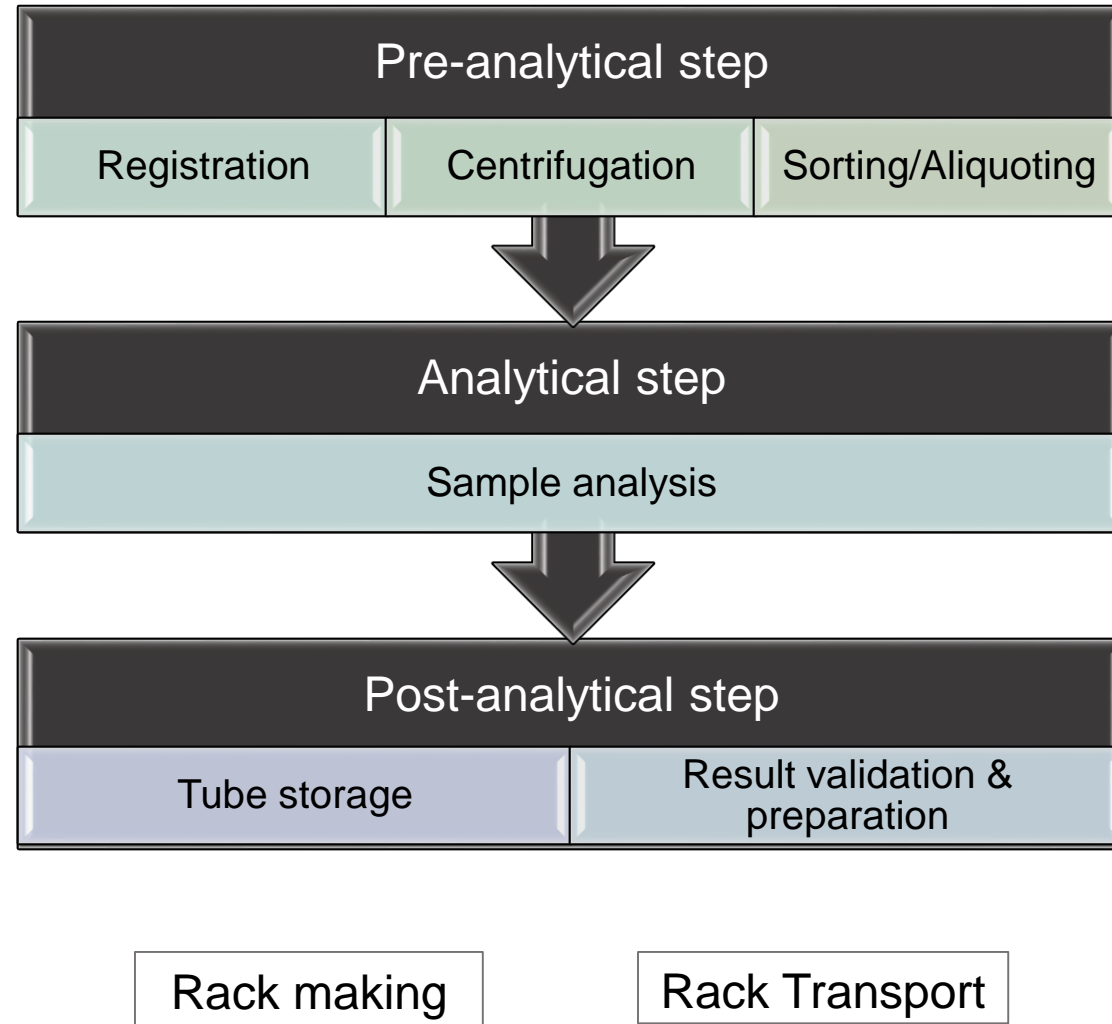


Table 3: Laboratory findings of the 400 patients at time of diagnosis and at the end of the study.

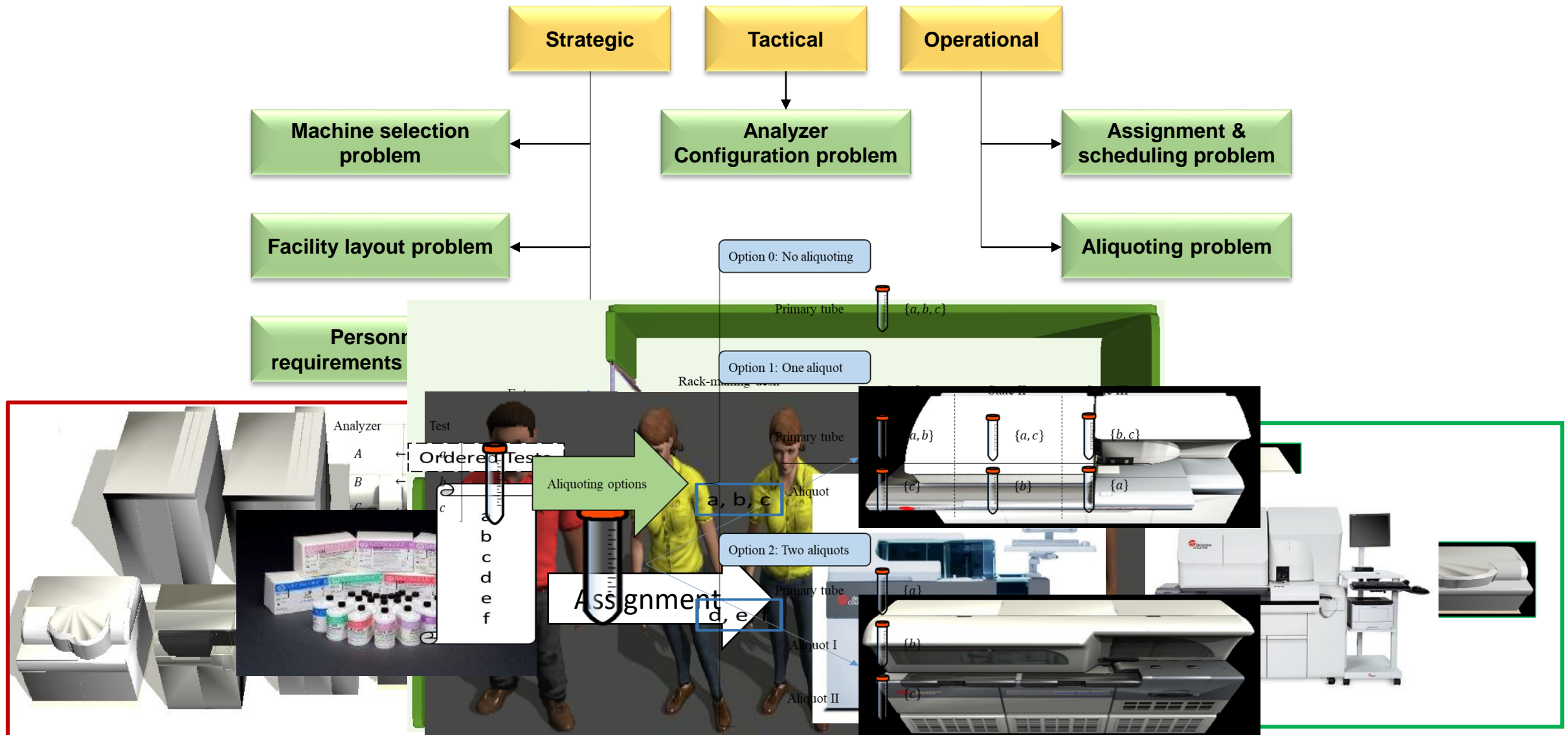
Parameter	At diagnosis	At the end of the study
WBC	15.2	12.5
Hb	11.5	13.2
Hct	32.5	38.1
PLT	185	210
RDW	14.5	13.8
MCV	85.5	90.2
MPV	10.2	11.5
PDW	12.5	11.8
FLC	0.8	0.7
FLC/ALB	0.015	0.012
FLC/IGG	0.005	0.004
FLC/IGM	0.002	0.001
FLC/IGK	0.001	0.001
FLC/IGL	0.001	0.001
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FLC/IGG99	0.001	0.001
FLC/IGG100	0.001	0.001



EXAMINATION SITE: MAIN PROCESS

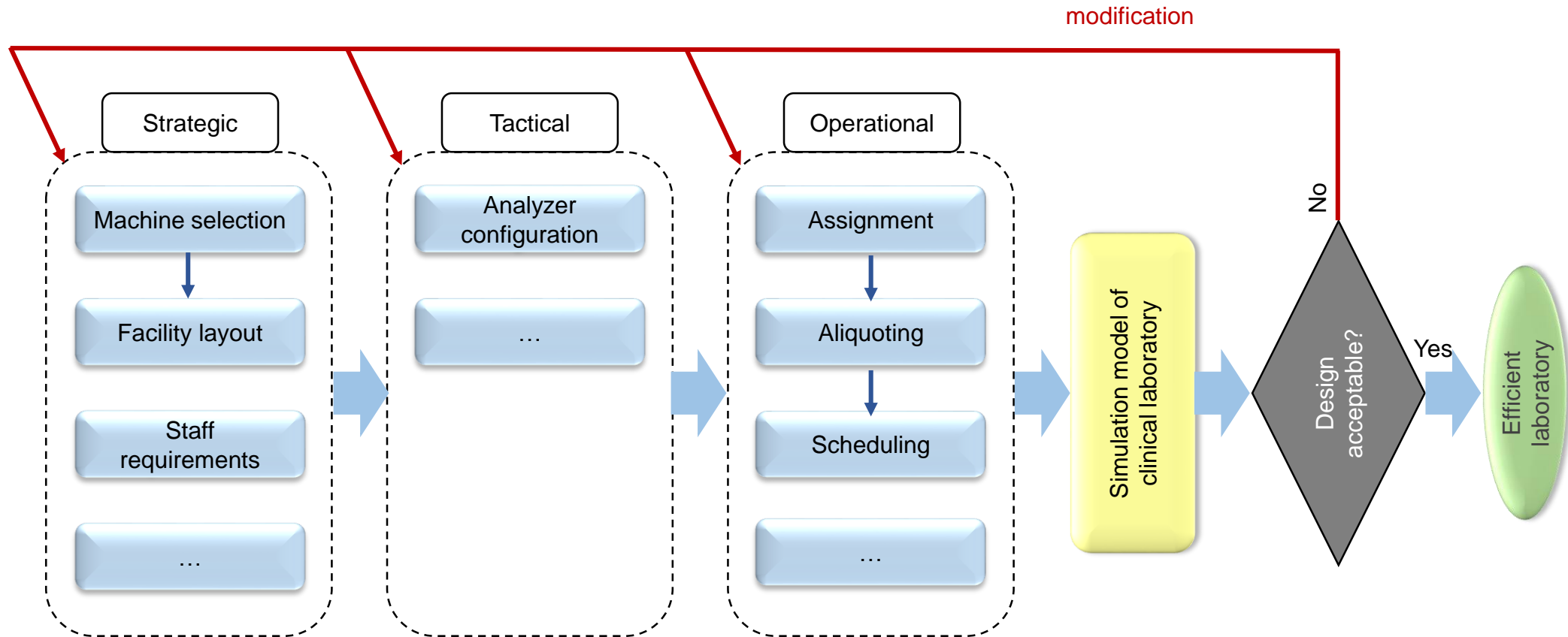


MAIN DECISION PROBLEMS IN CL DESIGN & PLANNING



PROPOSED FRAMEWORK

- Systematic, top-down, stepwise framework with recursive loop





CASE STUDY: REAL LABORATORY IN FRANCE

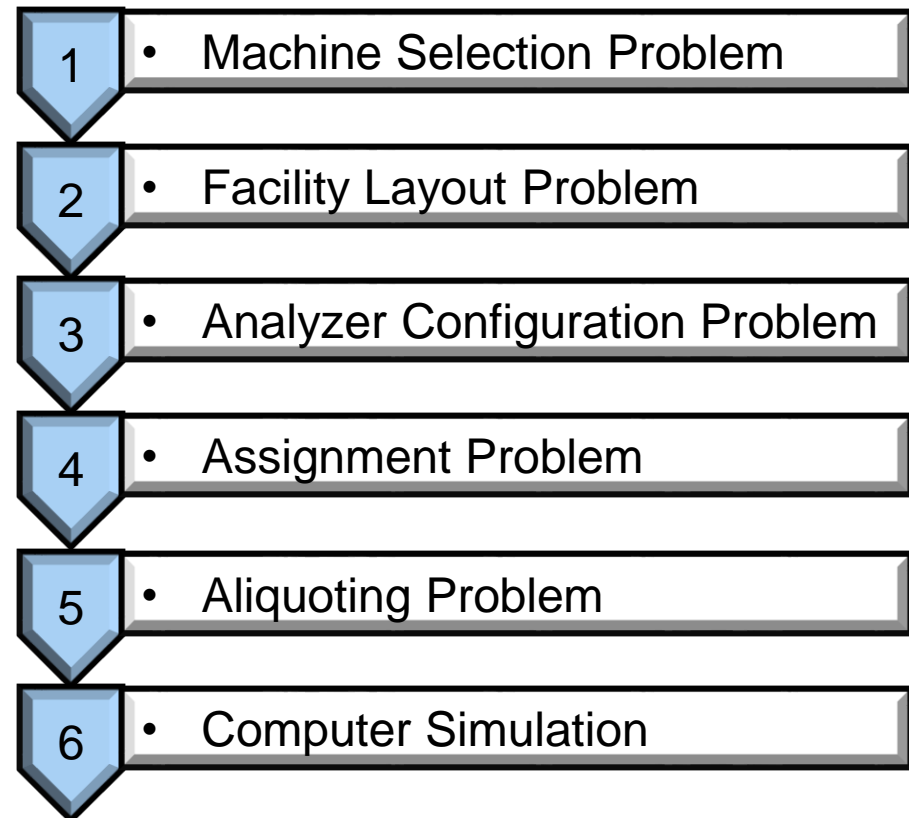
● Immunology and Chemistry disciplines

● Daily Demand characteristics

Demand - Tube	←	Total Number of tubes	3,847
		Number of Chemistry tubes	1,657
		Number of Immunology tubes	458
		Number of Imm-Ch tubes	1,732
Test types	←	Total number of test type	73
		Chemistry test type	40
		Immunology test type	32
Demand - Test	←	Total number of test requested	28,632
		Total number of chemistry tests	24,041
		Total number of Immunology tests	4,591

RESOLUTION APPROACHES AND TOOLS

- ❖ MIP models solved with **Cplex** solver in GAMS
- ❖ Multi-objectives models tackled by **weighted sum method**
- ❖ Heuristic developed in **Java**
- ❖ Data management tool developed in **Excel**



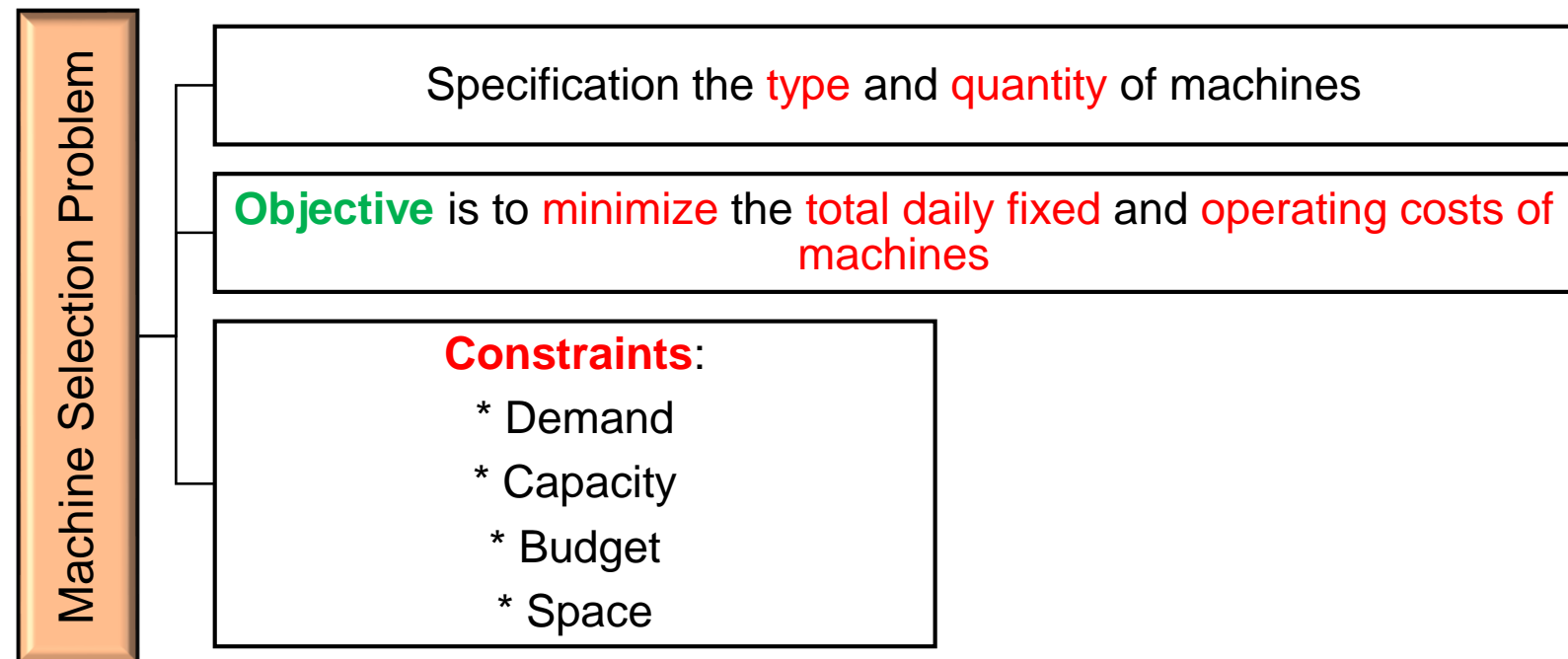


MACHINE SELECTION PROBLEM

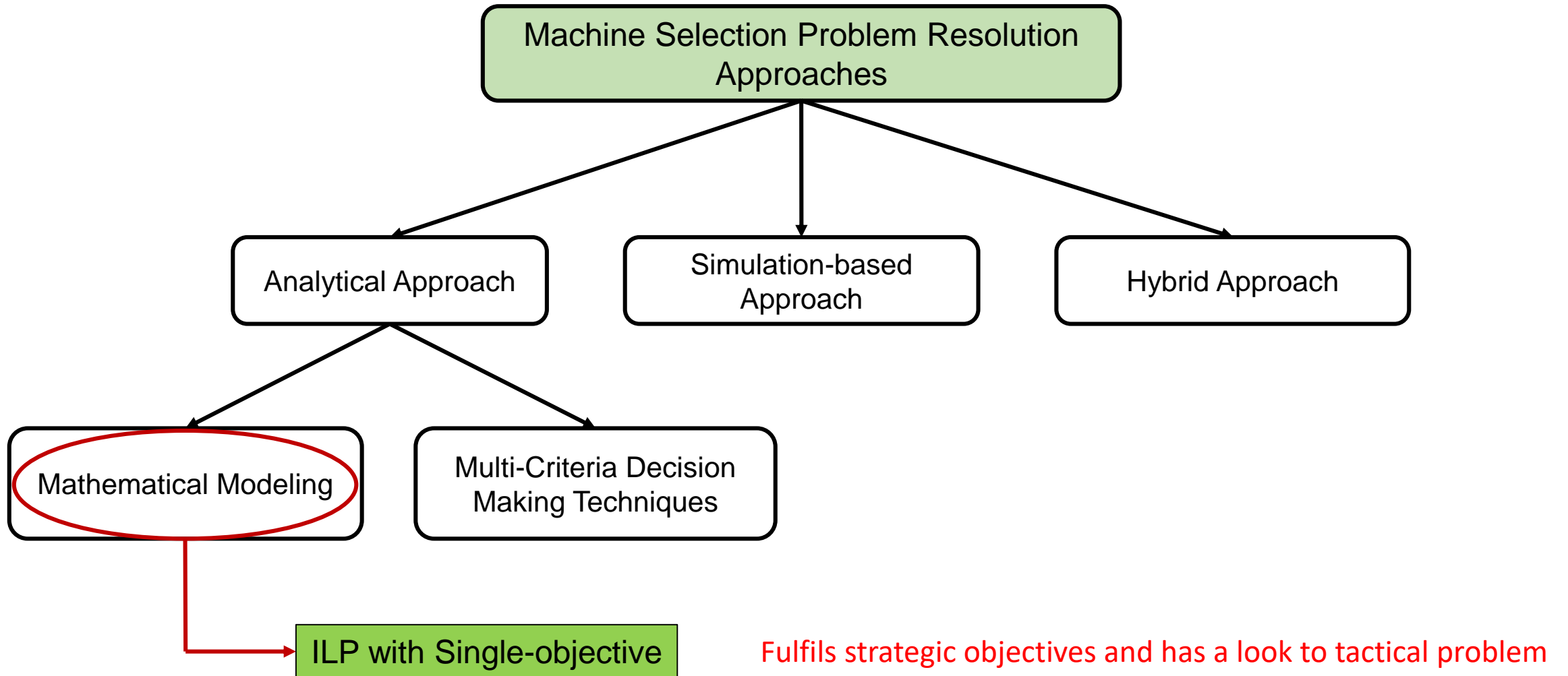
FOR CLINICAL LABORATORY

PROBLEM DESCRIPTION AND DEFINITION

- Type of machines in a laboratory
 - ✦ Analyzers: Immunology (e.g. DxIs), Chemistry (e.g. AUs), etc.
 - ✦ Non-analytical machines: Centrifuge, Sorter, etc.
- Problem definition



RESOLUTION APPROACHES FOR MACHINE SELECTION





PROPOSED MATHEMATICAL MODEL

$$\text{Min } \sum_{j \in M} FC_j u_j + \sum_{h \in H} \sum_{s \in Q} \sum_{j \in M^A} RC_{hsj} x_{hsj} + \sum_{h \in H} \sum_{j \in M^A} CC_{hj} y_{hj} \longrightarrow \text{Total machines fixed cost, Total configuration cost, Total calibration cost}$$

$$\text{s.t. } AOC_j \leq \tau_j g_j u_j; \quad \forall j \in M^A$$

$$AOC_j \leq \sum_{h \in H} \sum_{s \in Q} \delta_{hsj} x_{hsj}; \quad \forall j \in M^A \longrightarrow \text{Analyzer operational capacity}$$

$$\sum_{j \in M^d} AOC_j \geq \sum_{h \in H^d} \left(F_h + \sum_{j \in M^d} \alpha_{hj} y_{hj} \right); \quad \forall d \in D \longrightarrow \text{Demand satisfaction for all tests}$$

$$\sum_{j \in M^A} \sum_{s \in Q} \delta_{hsj} x_{hsj} \geq F_h + \sum_{j \in M^A} \alpha_{hj} y_{hj}; \quad \forall h \in H \longrightarrow \text{Demand satisfaction for each specific test type}$$

$$\sum_{h \in H} \sum_{s \in Q} \lambda_{hs} x_{hsj} \leq RK_j u_j; \quad \forall j \in M^A \longrightarrow \text{Analyzer reagent capacity constraint}$$

$$y_{hj} \leq HM_{hj}; \quad \forall h \in H, j \in M^A \longrightarrow \text{Analyzer test capability constraint}$$



PROPOSED MATHEMATICAL MODEL

- $$\sum_{s \in Q} \lambda_{hs} x_{hsj} \leq RK_j y_{hj}; \quad \forall h \in H, j \in M^A \quad \longrightarrow$$

Test availability in each analyzer
 - $$\sum_{j \in M^{NA-C}} \tau_j \varphi_j u_j \geq TTC \quad \longrightarrow$$

Demand satisfaction for centrifugation
 - $$\sum_{j \in M^{NA-AT}} \tau_j \varphi_j u_j \geq \eta \cdot TTA \quad \longrightarrow$$

Demand satisfaction for sorting
 - $$\sum_{j \in M} \psi_j u_j \leq A \quad \longrightarrow$$

Space constraint
 - $$\sum_{j \in M} PC_j u_j \leq \beta \quad \longrightarrow$$

Budget constraint
 - $$u_j \in \{0, 1\}; \quad \forall j \in M$$
 - $$x_{hsj} \geq 0 \text{ and integer}; \quad \forall h \in H, s \in Q, j \in M^A$$
 - $$y_{hj} \in \{0, 1\}; \quad \forall h \in H, j \in M^A$$
 - $$AOC_j \geq 0 \text{ and integer}; \quad \forall j \in M^A$$
- } \longrightarrow Type of decision variables

MACHINE SELECTION PROBLEM NUMERICAL RESULTS

	Laboratory daily working hours		
	7 hours	8 hours	9 hours
Selected Immunology analyzers	2 Dxl800	1 Dxl600 1 Dxl800	1 Dxl600 1 Dxl800
Selected Chemistry analyzers	1 AU480 1 AU5822	1 AU480 1 AU5822	1 AU480 1 AU5822
Selected Centrifuges	5 CentrifugeT1	5 CentrifugeT1	4 CentrifugeT1
Selected Automates	2 AutomateT1	1 AutomateT1	1 AutomateT1
Objective function value	51.766	51.071	50.983



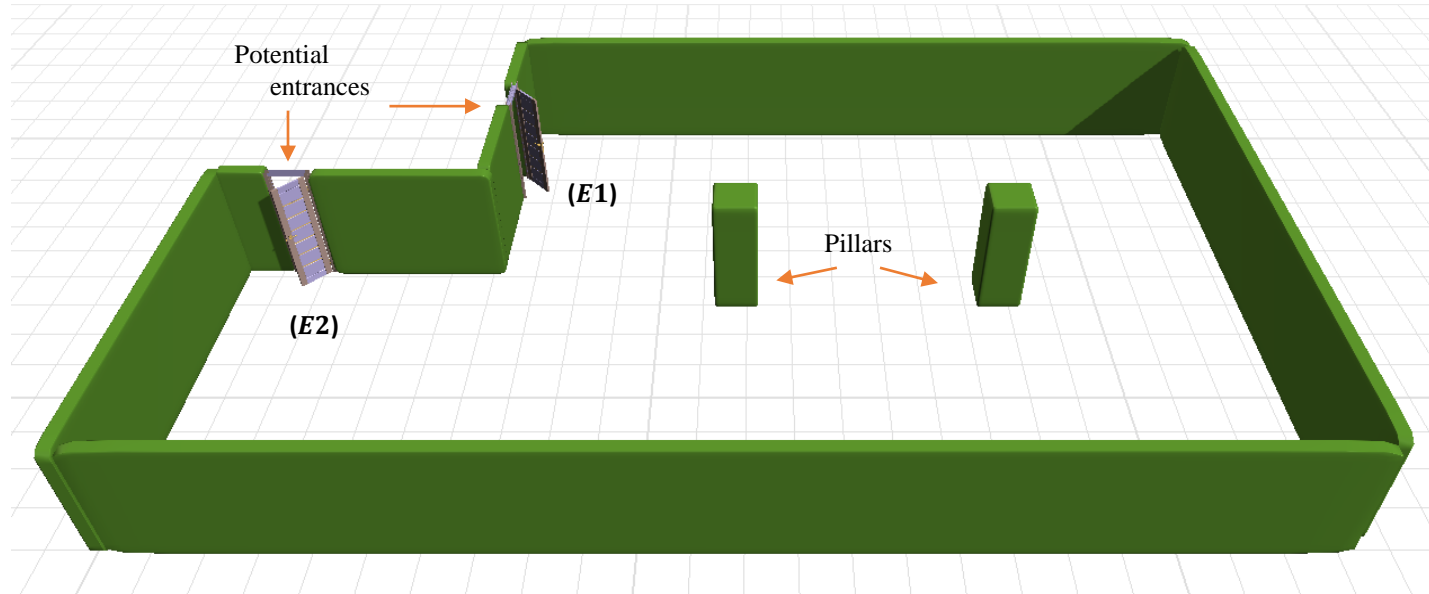
FACILITY LAYOUT PROBLEM

FOR CLINICAL LABORATORY

PROBLEM DESCRIPTION

Laboratory area

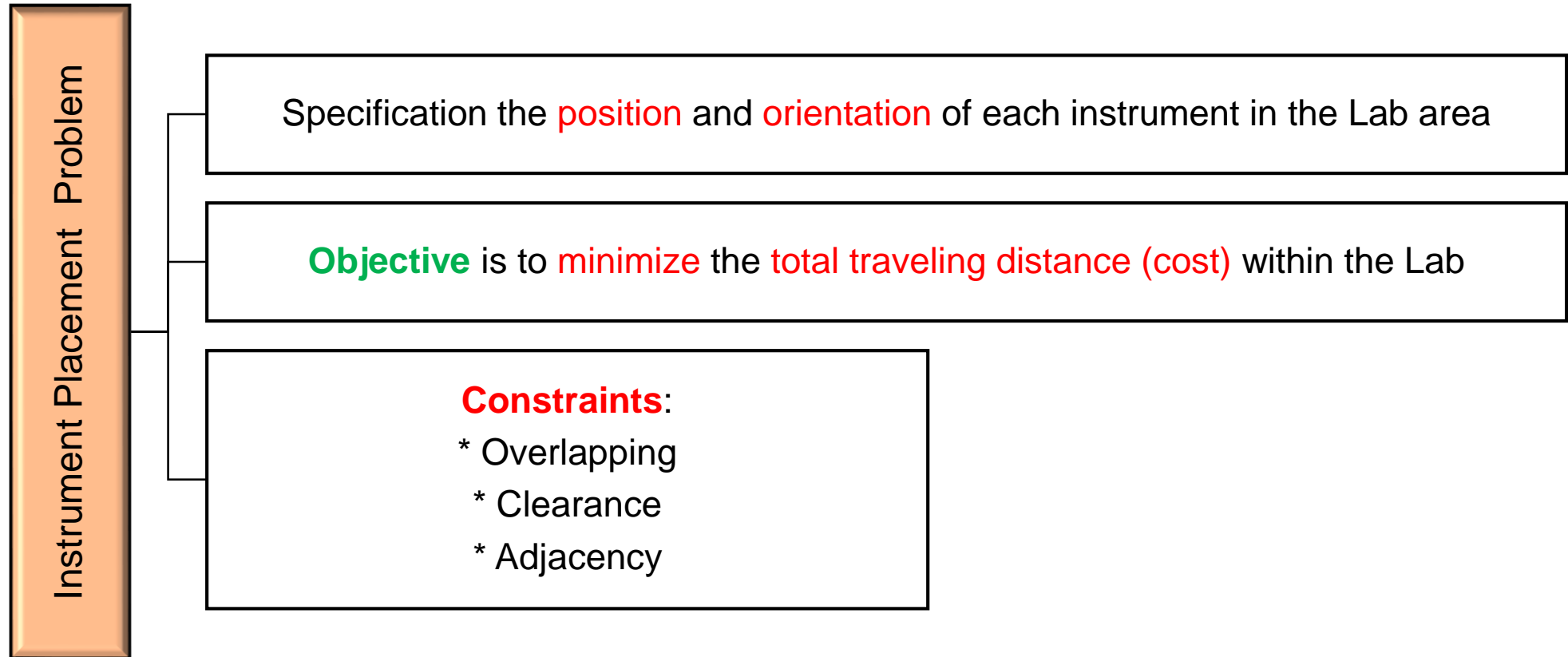
Instruments with different attributes



Optimization + Design



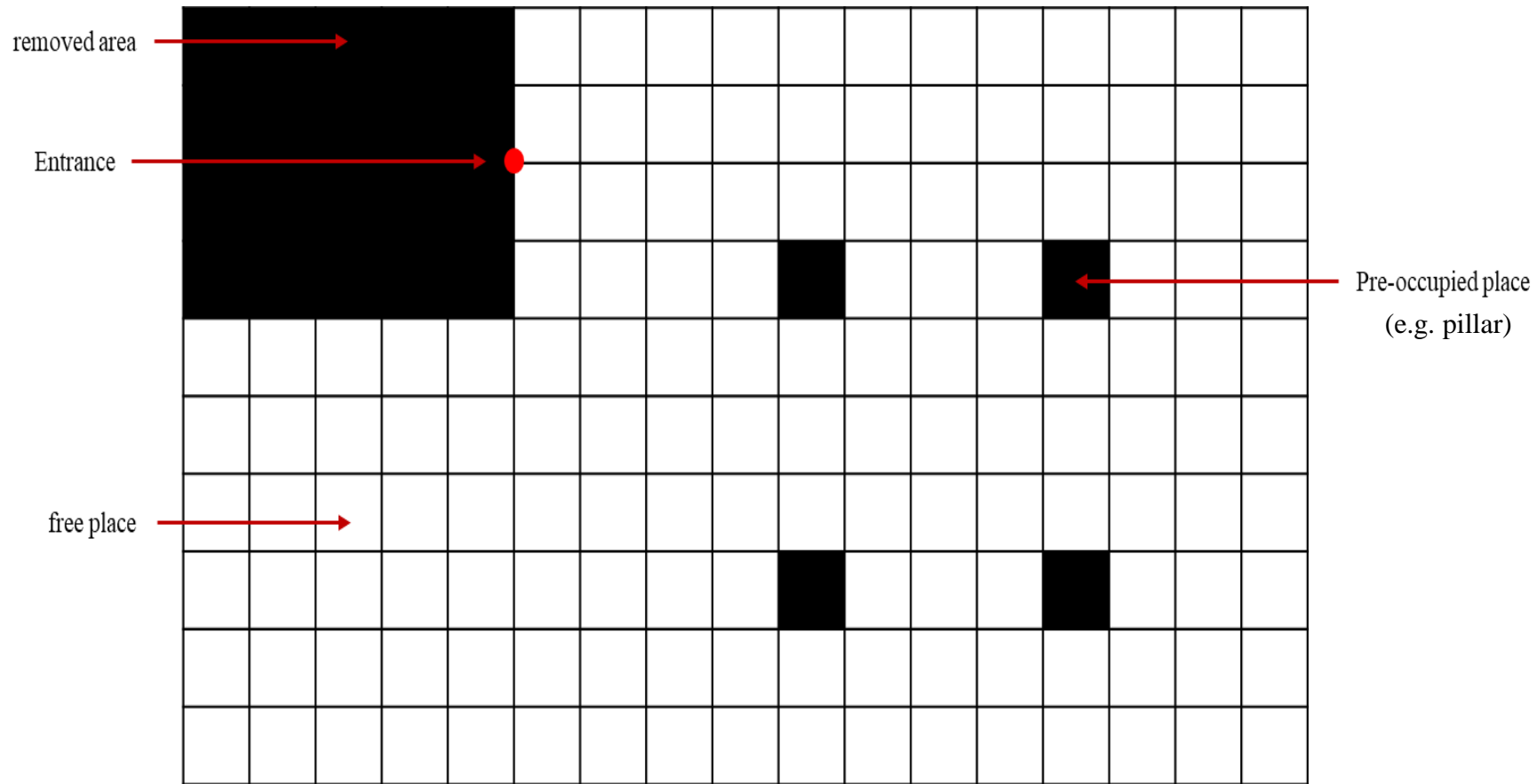
PROBLEM DEFINITION





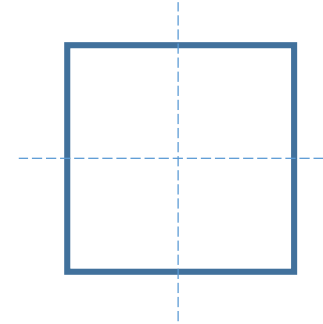
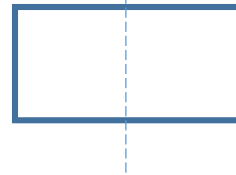
PROBLEM ASSUMPTIONS: LABORATORY AREA

- Single floor with any structure (simple or complex polygon)
- Given location for entrance and pre-occupied places (e.g. pillars)



PROBLEM ASSUMPTIONS: FACILITY

- All facilities are considered rectangular with known dimensions

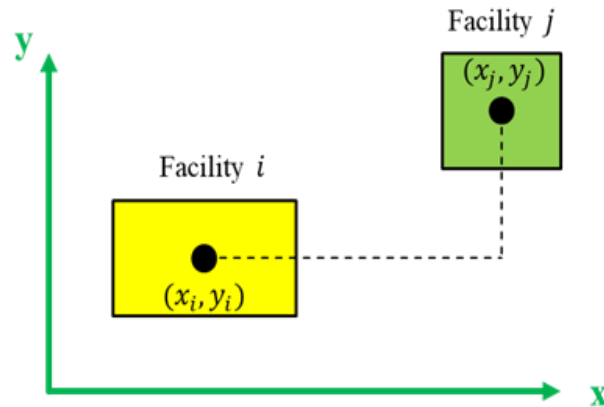


- A clearance is defined for each facility. This clearance is simply added to the size of the facility



PROBLEM ASSUMPTIONS: FACILITY

- Distance between two facilities: **Rectilinear**



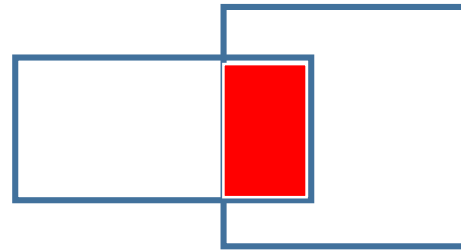
$$d_{ij} = |x_i - x_j| + |y_i - y_j|$$

- Relationship between each pair of facilities: **quantitative asymmetric** flow matrix
 - average number of **tubes** transported from one point to another
 - average number of time that an **operator** travels between two points

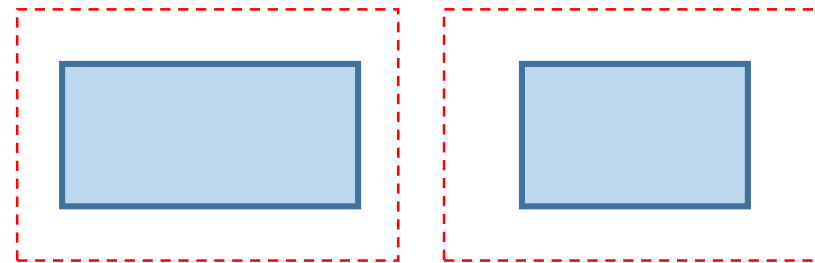


PROBLEM CONSTRAINTS

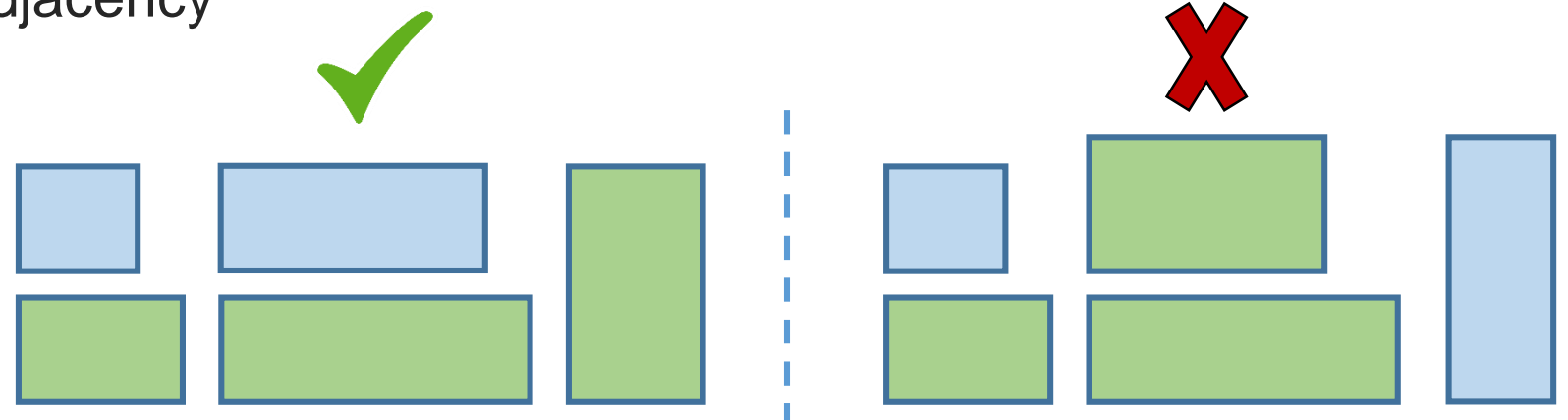
Physical: Overlapping



Technical: Clearance



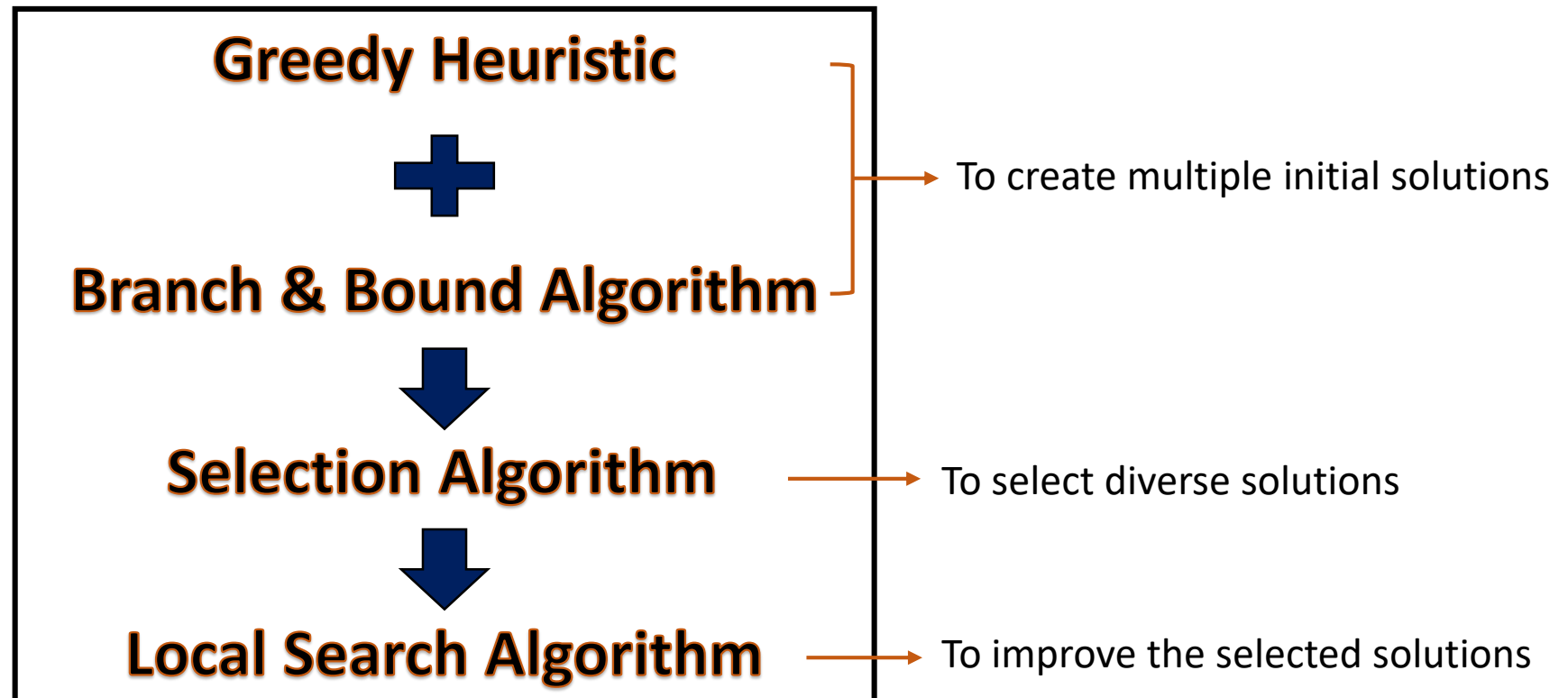
Organizational: Adjacency





RESOLUTION APPROACH

- **NP-hard** problem
- Structure of the proposed **hybrid heuristic** approach





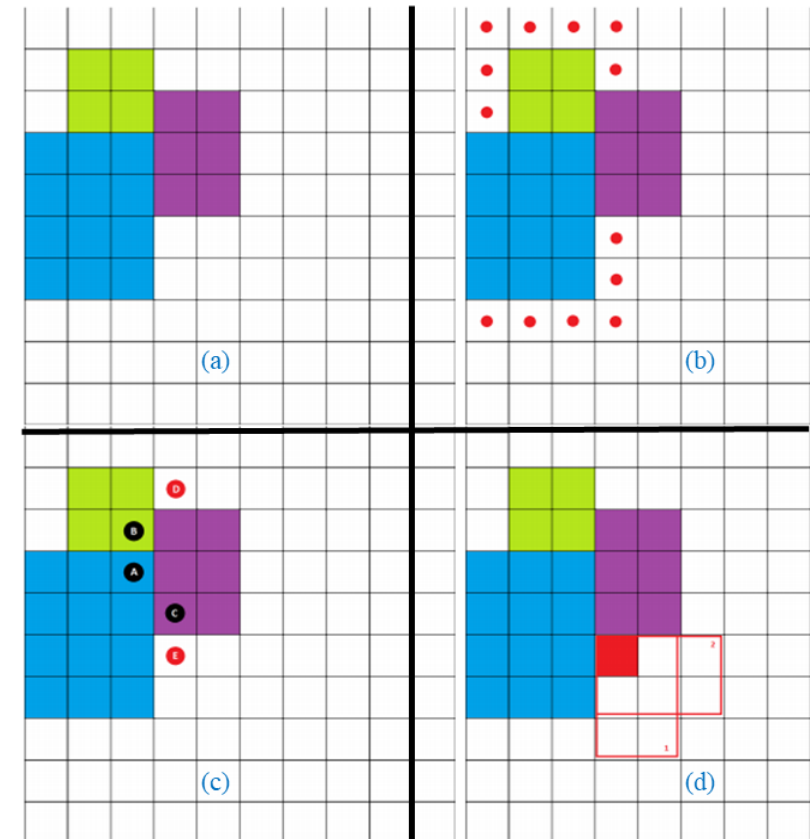
RESOLUTION APPROACH: GREEDY HEURISTIC

- Used to generate **initial solution**
- Quantitative **CORELAP** algorithm
- Made of two steps: (1) **Sorting** and (2) **Placement**

▣ Sorting rules

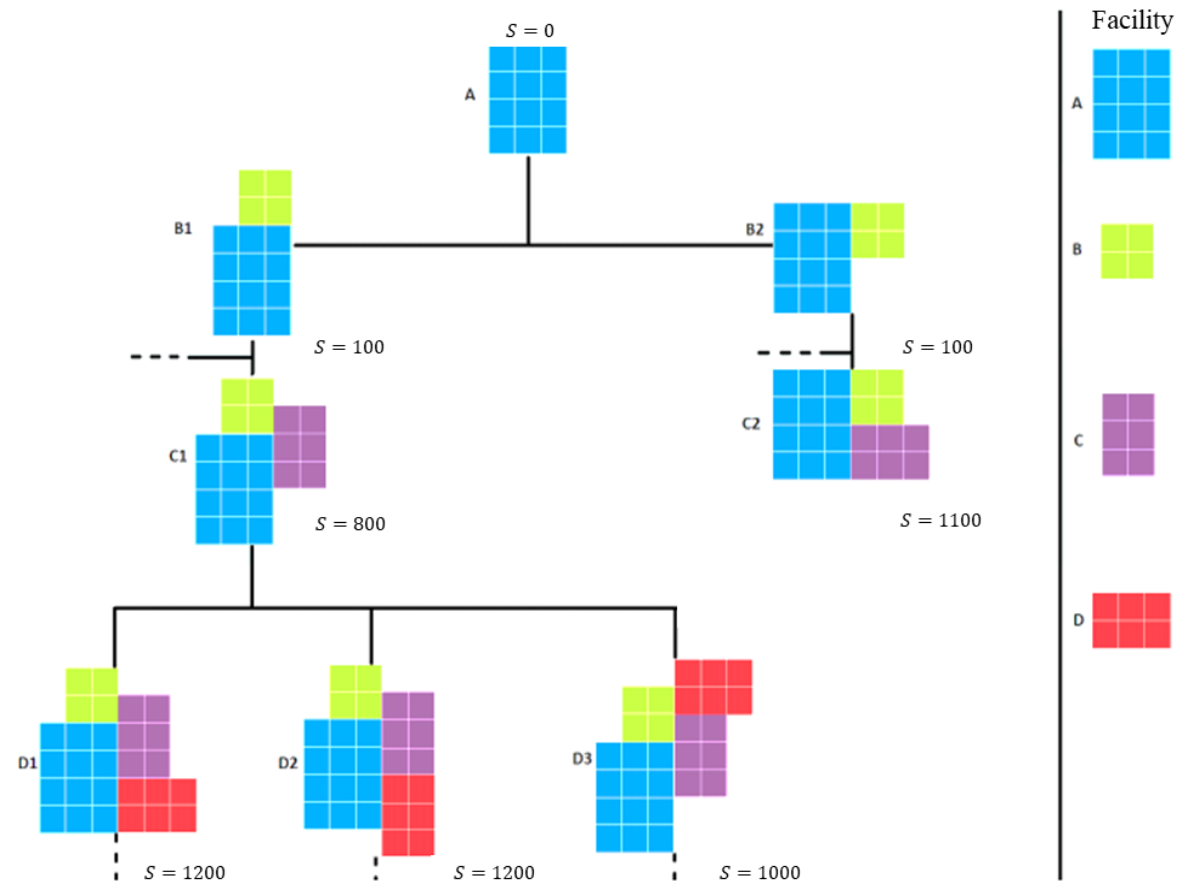
1. Facility '**registration desk**' is always the **first**
2. Facility with the **most connections** (from and to) with the previous added facility
3. Facility with the **highest total closeness rating** (TCR)

▣ Placement



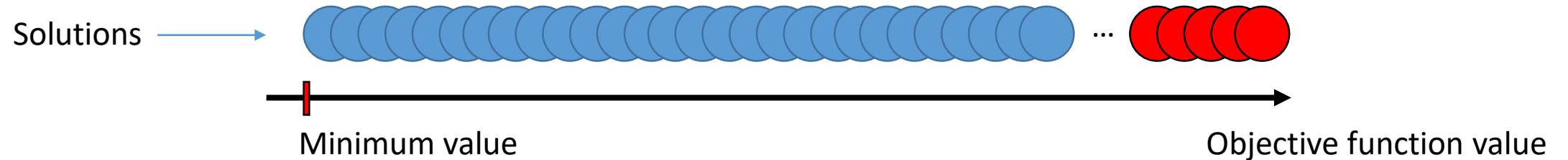
RESOLUTION APPROACH: GREEDY HEURISTIC + B&B

- Used to generate **multiple initial solutions**
- B&B manipulates in **placement phase**
- Branches are bounded regarding some rules



RESOLUTION APPROACH: SELECTION PHASE

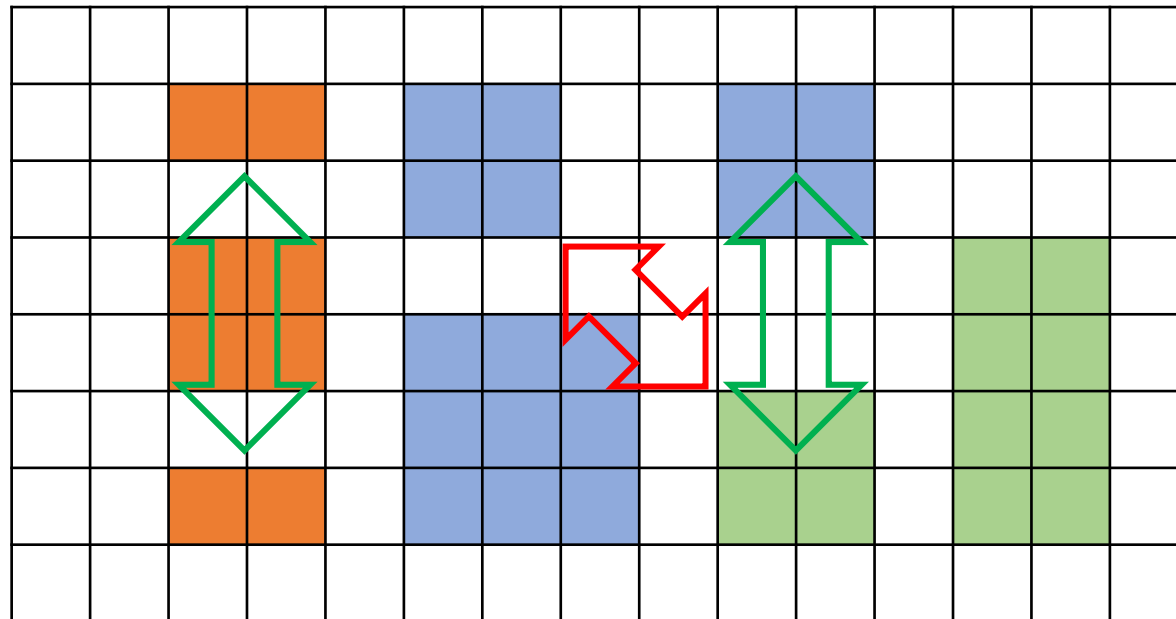
- Select best diverse solutions through comparing the obtained solutions
- **Diversity measure**: Distance between gravity centers of same-discipline facilities in 2 solutions
- Aims at providing **plenty of diverse design alternatives** for designers



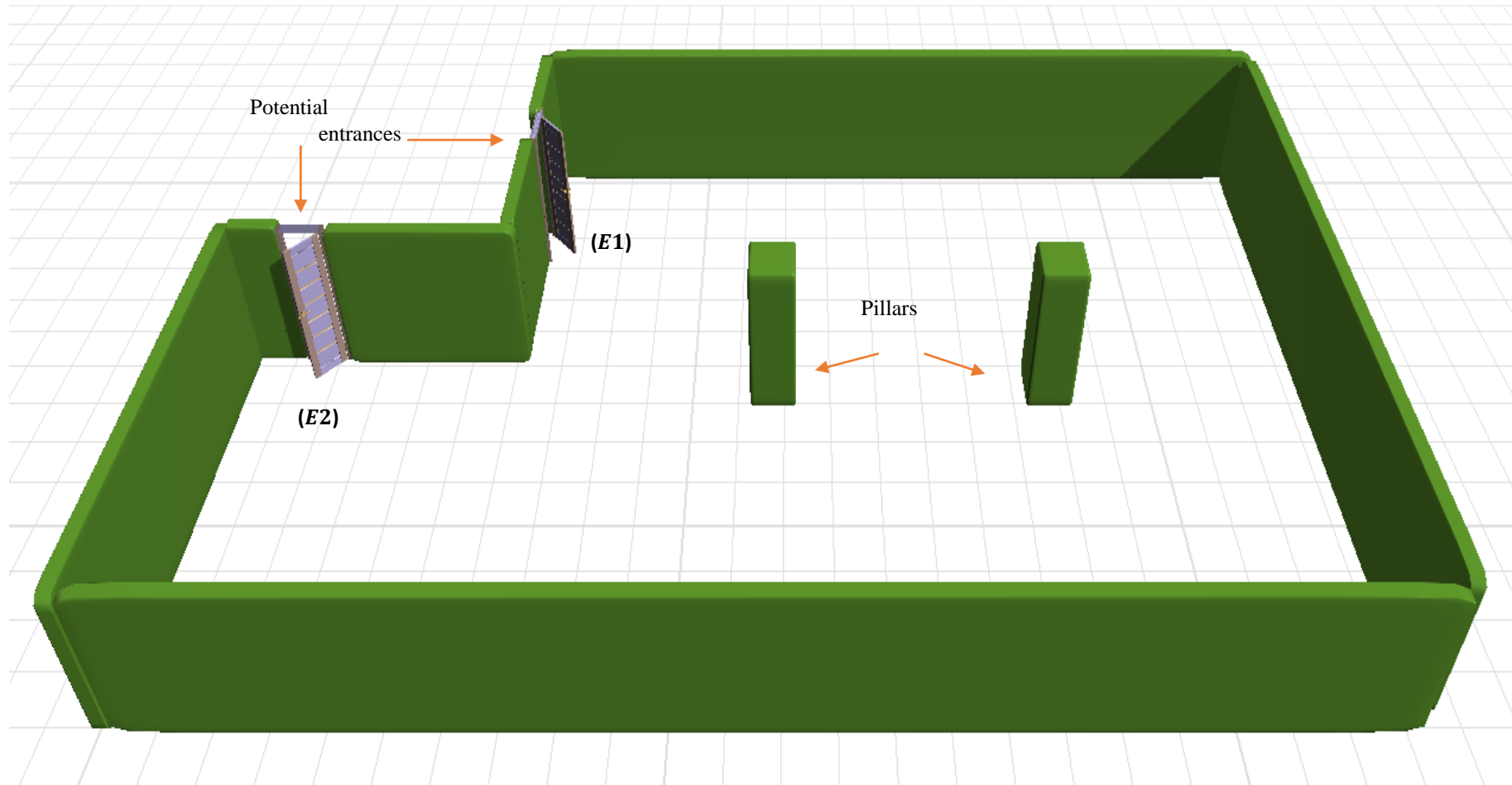
Selected Solutions

RESOLUTION APPROACH: LOCAL SEARCH PHASE

- Improving the selected solutions through **2-opt algorithm**
- 2-opt algorithm involves **swapping** facilities with **equal sizes**
- An acceptable swap leads to a solution with better value for objective function respecting constraints
- Feasible** and **infeasible** swaps:



CASE STUDY: LABORATORY AREA



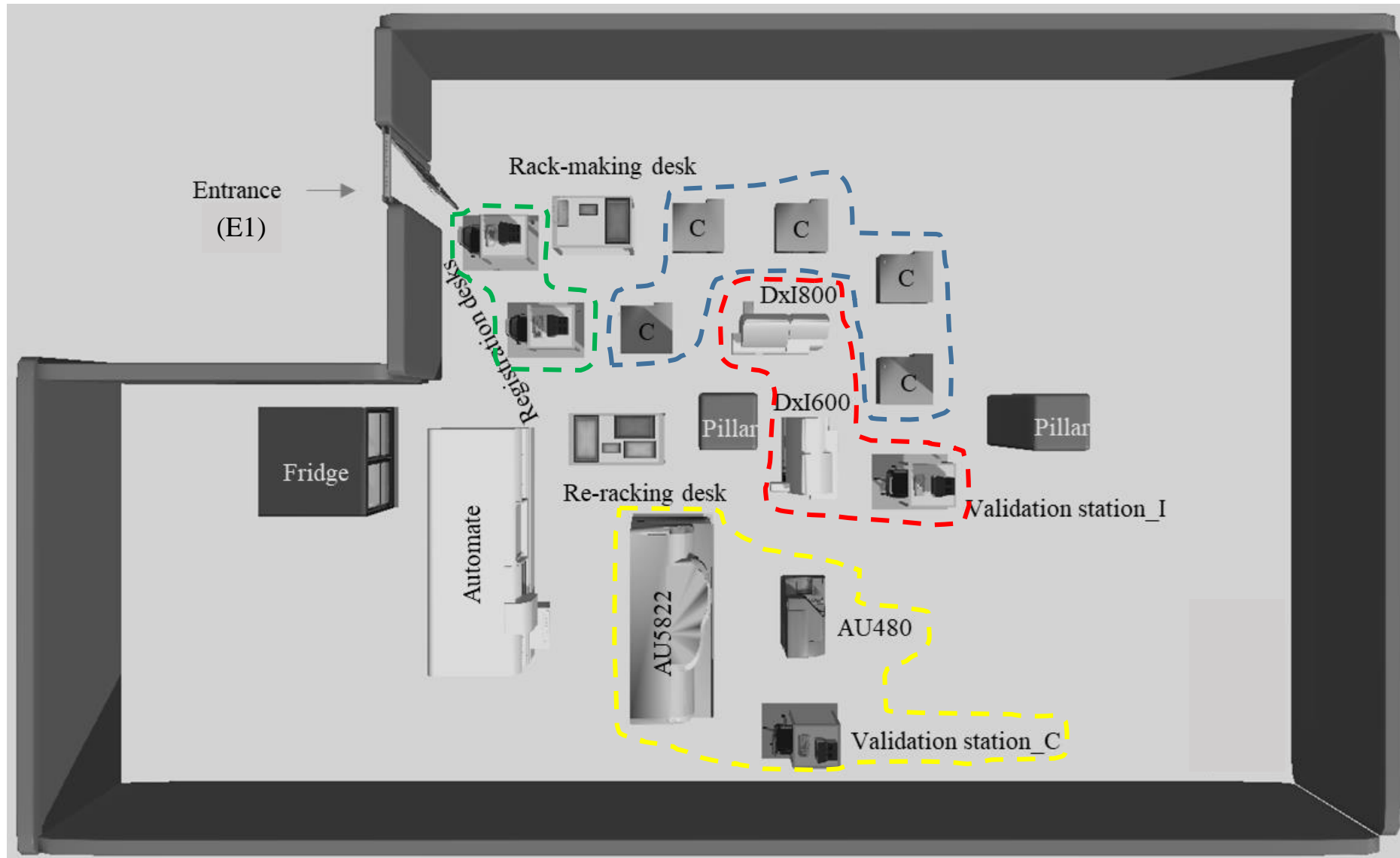
CASE STUDY: FACILITIES

- Selected machines + other necessary instruments

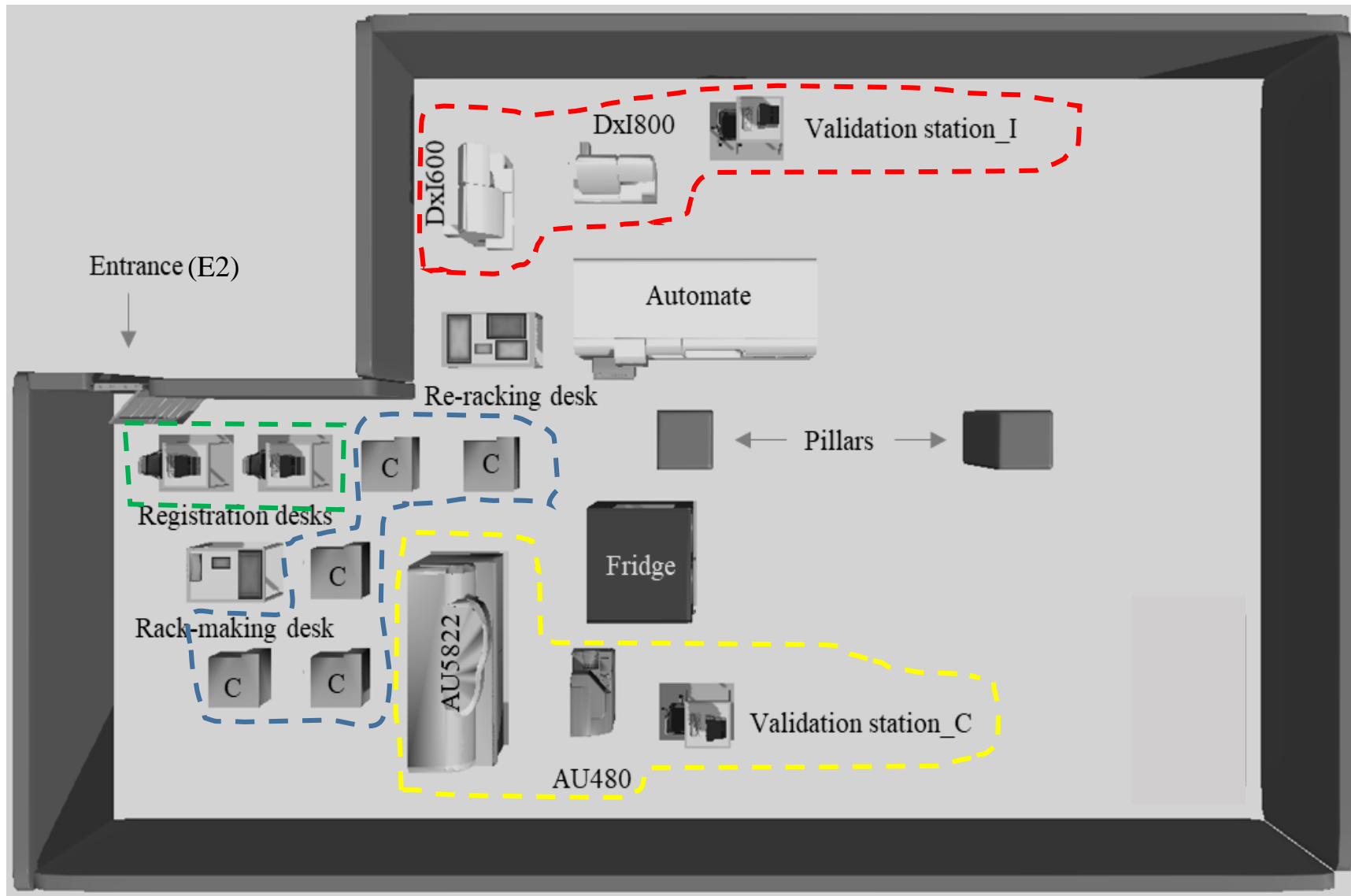
Facility	Number	Length (cm)	Width (cm)	Clearance (cm)
Registration desk	2	150	110	50
Rack-making desk_C	1	150	100	50
Centrifuge	5	100	100	70
Re-racking desk_A	1	180	100	50
Automate	1	450	170	100
AU480	1	145	77	100
AU5822	1	366	158	100
DxI600	1	171	97	100
DxI800	1	171	97	100
Validation station_I	1	150	110	50
Validation station_C	1	150	110	50
Fridge	1	200	200	100

17 facilities

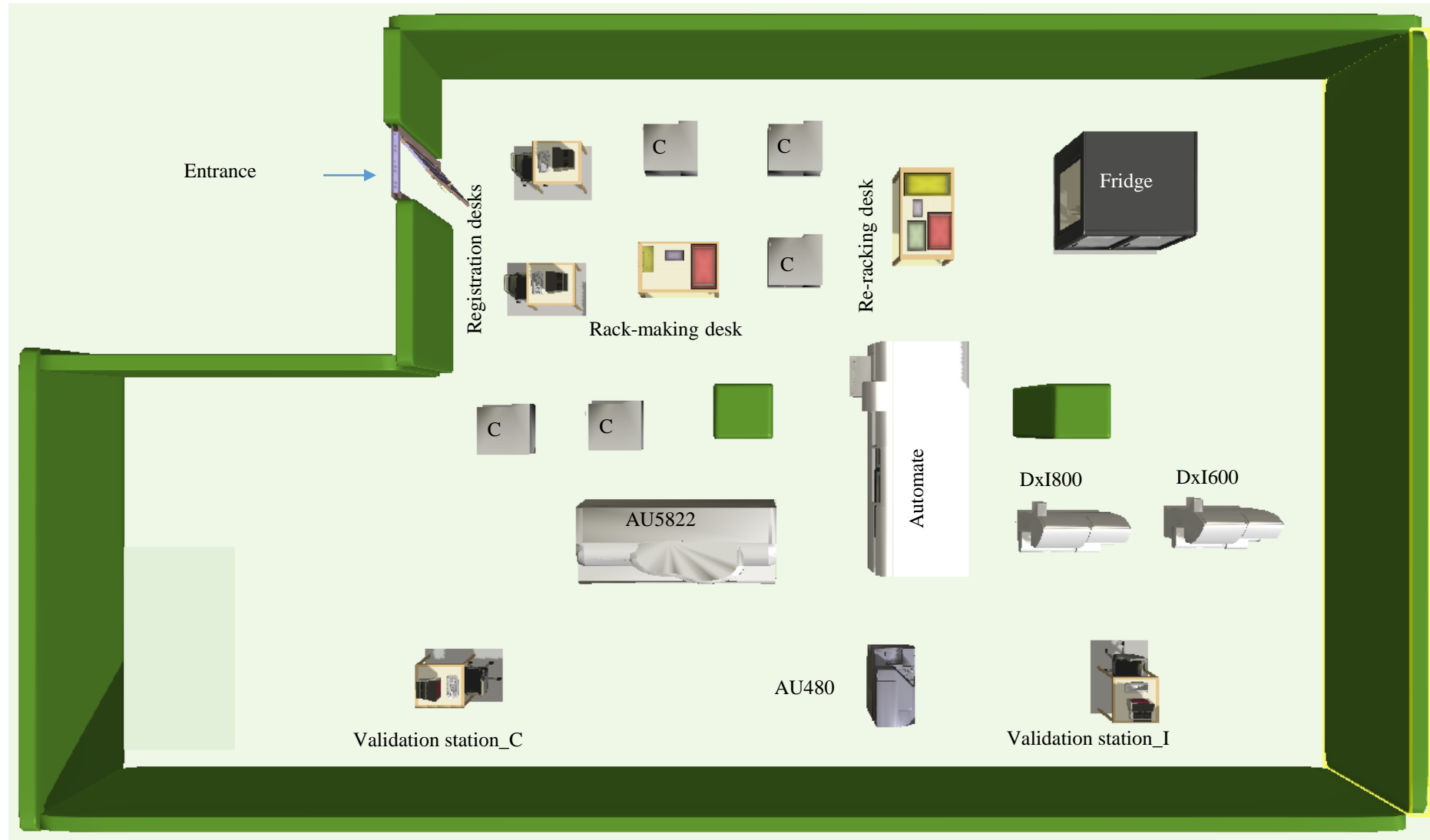
LAYOUT DESIGN OUTPUT (ENTRANCE E1)



LAYOUT DESIGN OUTPUT (ENTRANCE E2)



FINAL LAYOUT DESIGN WITH MANUPULATION





ANALYZER CONFIGURATION PROBLEM

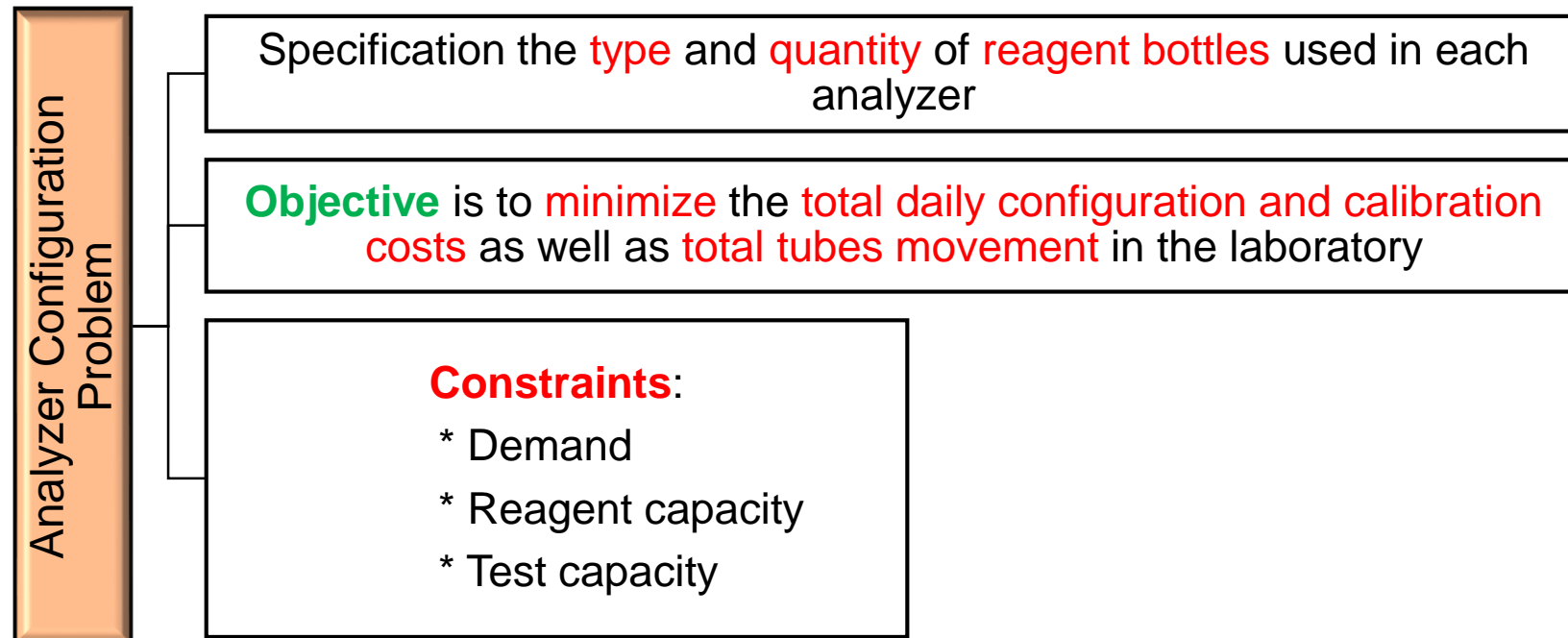
FOR CLINICAL LABORATORY

ANALYZER CONFIGURATION PROBLEM

Problem description



Problem definition



PROPOSED MATHEMATICAL MODELS

Single objective model

- Modeling idea: Machine selection model through fixing selection variables
- Input data: Test-based demand
- Objective: Minimizing total daily configuration and calibration costs

Bi-objective model

- Modeling idea:



- Input data: Tube-based demand
- Objective: **Minimizing total daily configuration and calibration costs** as well as **total tubs movement**

PROPOSED BI-OBJECTIVE MATHEMATICAL MODEL

Objective Functions

$$\text{Min } F1 = \sum_{h \in H} \sum_{s \in Q} \sum_{j \in M^A} RC_{hsj} w_{hsj} + \sum_{h \in H} \sum_{j \in M^A} CC_{hj} z_{hj}$$

Total configuration costs Total calibration costs

$$\text{Min } F2 = \sum_{i \in N} \sum_{j \in M} x_{ij}$$

Total tubes movement



PROPOSED MATHEMATICAL MODEL: CONSTRAINTS

$\sum_{j \in M} y_{hij} = TH_{ih} ; \forall i \in N, h \in H$	}	→	Assignment constraints
$y_{hij} \leq x_{ij} ; \forall i \in N, j \in M, h \in H$			
$\sum_{h \in H} \sum_{s \in Q} \lambda_{hs} w_{hsj} \leq RK_j ; \forall j \in M$		→	Analyzer reagent position constraint
$\sum_{s \in Q} \lambda_{hs} w_{hsj} \leq RK_j z_{hj} ; \forall j \in M, h \in H$		→	Test availability in each analyzer
$z_{hj} \leq HM_{hj} ; \forall h \in H, j \in M$		→	Analyzer test capability constraint
$\sum_{i \in N} y_{hij} \leq \sum_{s \in Q} \delta_{hsj} w_{hsj} - \sigma_{hj} z_{hj} ; \forall j \in M, h \in H$		→	Analyzer reagent capacity constraint
$\sum_{h \in H} \sum_{i \in N} y_{hij} \leq \tau_j g_j ; \forall j \in M$		→	Analyzer nominal capacity
$\sum_{h \in H^d} \sum_{i \in N} y_{hij} \geq \left(\frac{g_j}{\sum_{j \in M^d} g_j} - \theta_d \right) \times \sum_{h \in H^d} F_h ; \forall d \in D, j \in M^d$		→	Lower bound for test assignment to analyzers
$x_{ij} \in \{0,1\}, \forall i \in N; j \in M$	}	→	Type of decision variables
$y_{hij} \in \{0,1\}, \forall h \in H; i \in N; j \in M$			
$w_{hsj} \geq 0 \text{ and integer}, \forall h \in H; s \in Q; j \in M$			
$z_{hj} \in \{0,1\}, \forall h \in H; j \in M$			

ANALYZER CONFIGURATION: NUMERICAL RESULTS

Existing analyzers

- Immunology analyzers: Dxl600, Dxl800
- Chemistry analyzers: AU480, AU5822

weight $\leftarrow \pi$	F_1	F_2	Relative gap (%)	Run time (sec)
0	65.547	5,579	0	169.45
0.3	49.191	5,602	2.38	10,800
0.5	49.067	5,607	2.11	10,800
0.7	48.997	5,690	2.57	10,800
1	48.799	11,158	0	19.78

ANALYZER CONFIGURATION: PART OF OUTPUT

Test/Reagent type	Bottle size	Analyzers			
		AU480	AU5822	Dxl600	Dxl800
ALT	Small	1	6		
AST	Small	1	6		
UricAcidu	Small	1			
UricAcid	Small		2		
CK	Small		1		
Calcium	Large		3		
Creatinine	Small	1	2		
CRP	Large		2		
Triglyceride	Small		6		
UREA	Small	1	1		
...
freePSA	small			1	1
PSA-Hyb	small			1	7
FRT3	small			1	1
FRT4	small			1	5
Testo	small			1	
GToxo	small			4	1
IgM-Toxo	small			4	1
TropI	small				1
TSH	Small			2	10
...



ASSIGNMENT PROBLEM

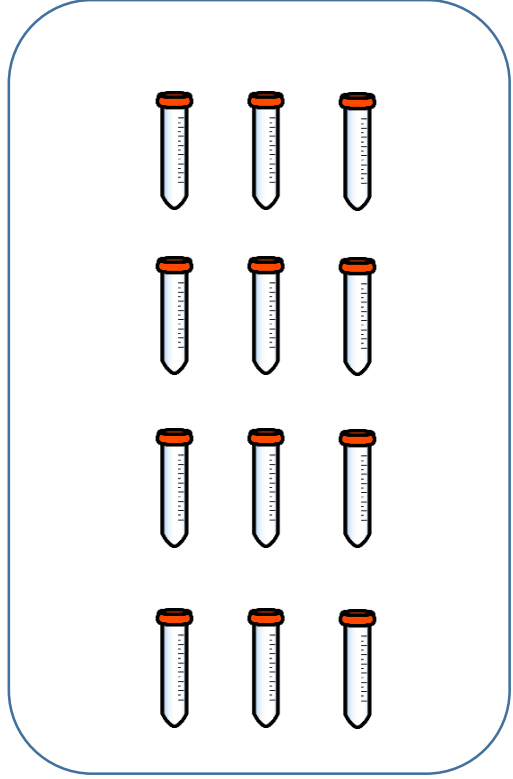
FOR CLINICAL LABORATORY



PROBLEM DESCRIPTION

[Tube-Test matrix]

Sample Tubes



Assignment

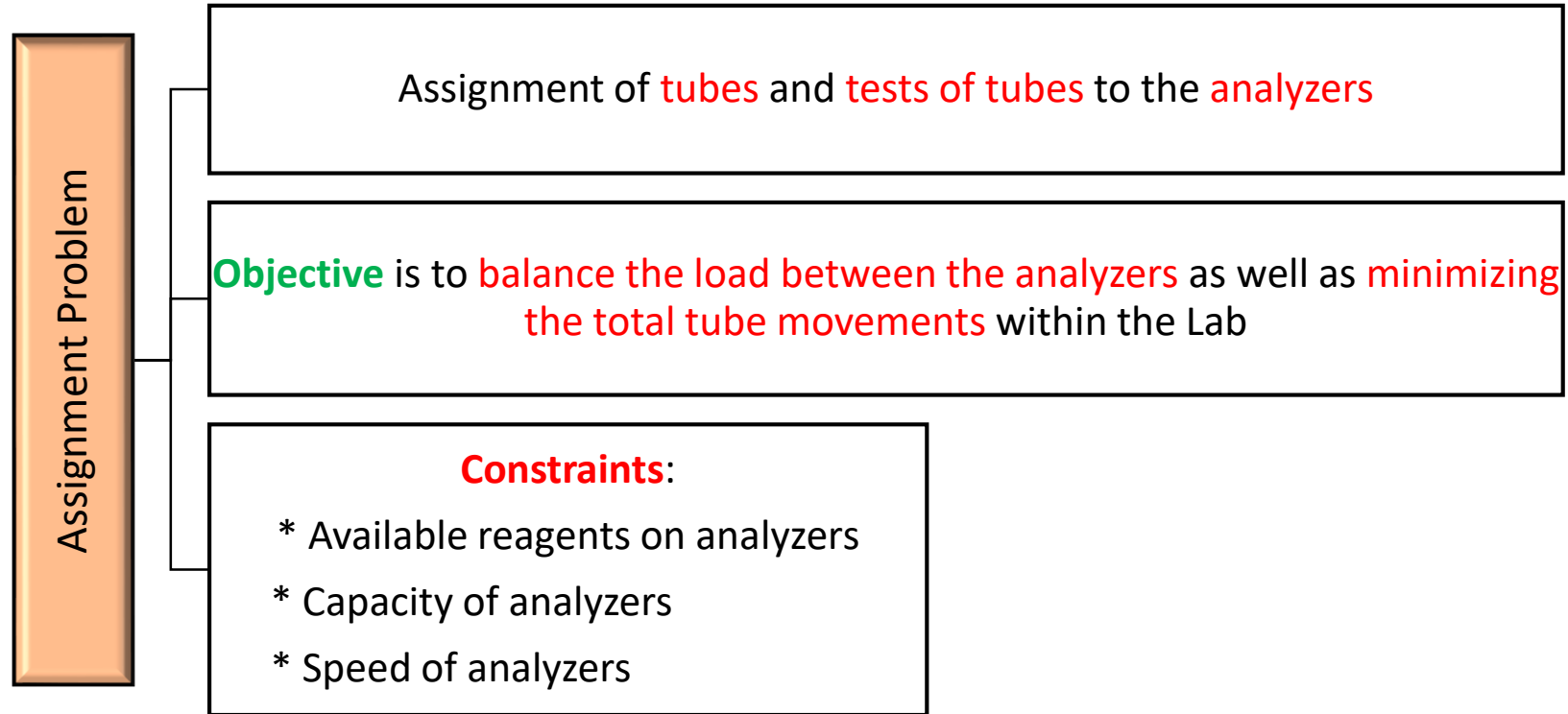
Tubes and Test of tubes

Analyzers



[Analyzer-Test matrix]

PROBLEM DEFINITION



!!! Note on load balancing!!!

Considering **capacity** and **speed** of analyzers as well as **reagent availability**, load balancing among analyzers of a same discipline is defined based on:

- Number of **tubes** assigned to the analyzers
- Number of **tests** assigned to the analyzers

PROPOSED **MULTI-OBJECTIVE** MATHEMATICAL MODEL

Objective Functions

Load balancing _ Tubes

$$\text{Min } F1 = \sum_{j,j' \in M^{IMM}} (z_{jj'} + v_{jj'}) + \sum_{j,j' \in M^{CHEM}} (z_{jj'} + w_{jj'})$$

Load balancing _ Tests

$$\text{Min } F2 = \sum_{j,j' \in M^{IMM}} \mu_{jj'} + \sum_{j,j' \in M^{CHEM}} \mu_{jj'}$$

Total tubes movement (cost)

$$\text{Min } F3 = \sum_{i \in CL^{IMM}} \sum_{j \in M} c_i x_{ij} + \sum_{i \in CL^{CHEM}} \sum_{j \in M} c_i x_{ij} + \sum_{i \in CL^{IMCH}} \sum_{j \in M} c_i x_{ij}$$



PROPOSED MATHEMATICAL MODEL: CONSTRAINTS

$$\sum_{j \in M} y_{hij} = TH_{ih} ; \forall i \in N, h \in H$$

$$y_{hij} \leq x_{ij} ; \forall i \in N, j \in M, h \in H$$



Assignment constraints

$$\sum_{h \in H} \sum_{s \in Q} \lambda_{hs} w_{hsj} \leq RK_j ; \forall j \in M$$



Analyzer reagent position constraint

$$\sum_{i \in N} \sum_{h \in H} y_{hij} \leq g_j \tau_j ; \forall j \in M$$



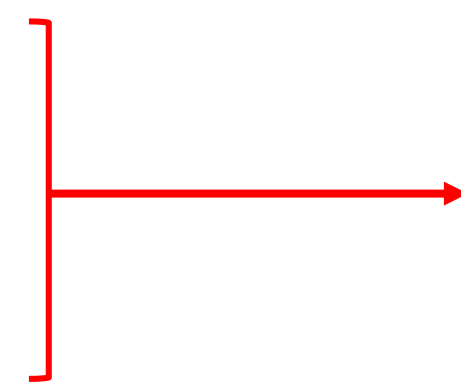
Analyzer nominal capacity constraint

$$\sum_{i \in CL^{IMM}} x_{ij} = \alpha_j ; \forall j \in M^{IMM}$$

$$\sum_{i \in CL^{IMCH}} x_{ij} = \lambda_j ; \forall j \in M^{IMM}$$

$$\sum_{i \in CL^{CHEM}} x_{ij} = \beta_j ; \forall j \in M^{CHEM}$$

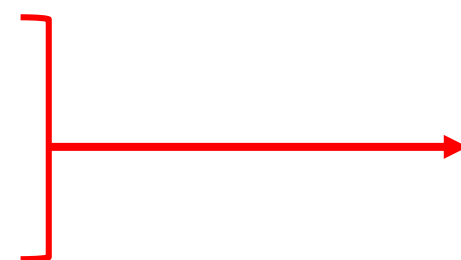
$$\sum_{i \in CL^{IMCH}} x_{ij} = \eta_j ; \forall j \in M^{CHEM}$$



Total number of tubes assigned to each analyzer from different class of tubes

$$\sum_{h \in H} \sum_{i \in N} y_{hij} = \rho_j ; \forall j \in M^{IMM}$$

$$\sum_{h \in H} \sum_{i \in N} y_{hij} = \varphi_j ; \forall j \in M^{CHEM}$$



Total number of tests assigned to each analyzer



PROPOSED MATHEMATICAL MODEL: CONSTRAINTS

$$\begin{cases} \frac{1}{g_j} \rho_j \leq \mu_{jj'} \\ \frac{1}{g_{j'}} \rho_{j'} \leq \mu_{jj'} \end{cases} ; \forall j, j' \in M^{IMM}, j < j'$$

$$\begin{cases} \frac{1}{g_j} \varphi_j \leq \mu_{jj'} \\ \frac{1}{g_{j'}} \varphi_{j'} \leq \mu_{jj'} \end{cases} ; \forall j, j' \in M^{CHEM}, j < j'$$

$$\begin{cases} \frac{1}{k_j} \alpha_j \leq z_{jj'} \\ \frac{1}{k_{j'}} \alpha_{j'} \leq z_{jj'} \end{cases} ; \forall j, j' \in M^{IMM}, j < j'$$

$$\begin{cases} \frac{1}{k_j} \lambda_j \leq v_{jj'} \\ \frac{1}{k_{j'}} \lambda_{j'} \leq \frac{1}{k_{j'}} v_{jj'} \end{cases} ; \forall j, j' \in M^{IMM}, j < j'$$

$$\begin{cases} \frac{1}{k_j} \beta_j \leq z_{jj'} \\ \frac{1}{k_{j'}} \beta_{j'} \leq z_{jj'} \end{cases} ; \forall j, j' \in M^{CHEM}, j < j'$$

$$\begin{cases} \frac{1}{k_j} \eta_j \leq w_{jj'} \\ \frac{1}{k_{j'}} \eta_{j'} \leq w_{jj'} \end{cases} ; \forall j, j' \in M^{CHEM}, j < j'$$

Load balancing constraints on analyzers in terms of tests

Load balancing constraints on analyzers in terms of tubes

ASSIGNMENT: NUMERICAL RESULTS

Existing analyzers

■ Immunology analyzers: Dxl600, Dxl800

■ Chemistry analyzers: AU480, AU5822

weights ←

π_1	π_2	π_3	F_1	F_2	F_3	Relative gap (%)	Run time (sec)
1	0	0	4.8325	13.686	17,387	0	5.02
0	1	0	18.562	13.259	31,186	0	5.32
0	0	1	5.985	13.542	15,987	0	6.66
0.2	0.3	0.5	5.2	13.259	16,217	0	10.12
0.2	0.2	0.6	5.611	13.260	16,053	0	8.08
0.3	0.1	0.6	5.2	13.260	16,220	0	7.5
0.3	0.3	0.4	5.161	13.26	16,242	0	7.98
0.4	0.1	0.5	5.161	13.259	16,242	0	15.26



ASSIGNMENT: OUTPUTS (TUBE-ANALYZER ASSIGNMENT)

Tube	AU480	AU5822	Dxl600	Dxl800
T1		1		
T2		1		
T3		1		
T4		1		
T5	1	1		
T6	1			
T7		1		
...
T1663				1
T1664				1
T1665			1	
T1666			1	1
T1667			1	1
T1668				1
...
T2116		1		1
T2117		1	1	
T2118	1			1
T2119		1	1	
T2120		1	1	
T2121	1			1
...

ASSIGNMENT: OUTPUTS (TUBE TEST-ANALYZER ASSIGNMENT)

Test Name	Tube	AU480	AU5822	Dxl600	Dxl800
ALT	T1		1		
AST	T1		1		
T-Bilirubin	T1		1		
Creatinine	T1000	1			
Glucose	T1000	1			
Ferritin	T3525				1
TSH	T3525				1
ALT	T3529	1			
AST	T3529	1			
HBc-Ab	T3529			1	
HBsAb	T3529			1	
HBsAgV3	T3529			1	
...



ALIQUOTING PROBLEM

FOR CLINICAL LABORATORY







New laboratory process &
decision problem






PROBLEM DESCRIPTION AND DEFINITION

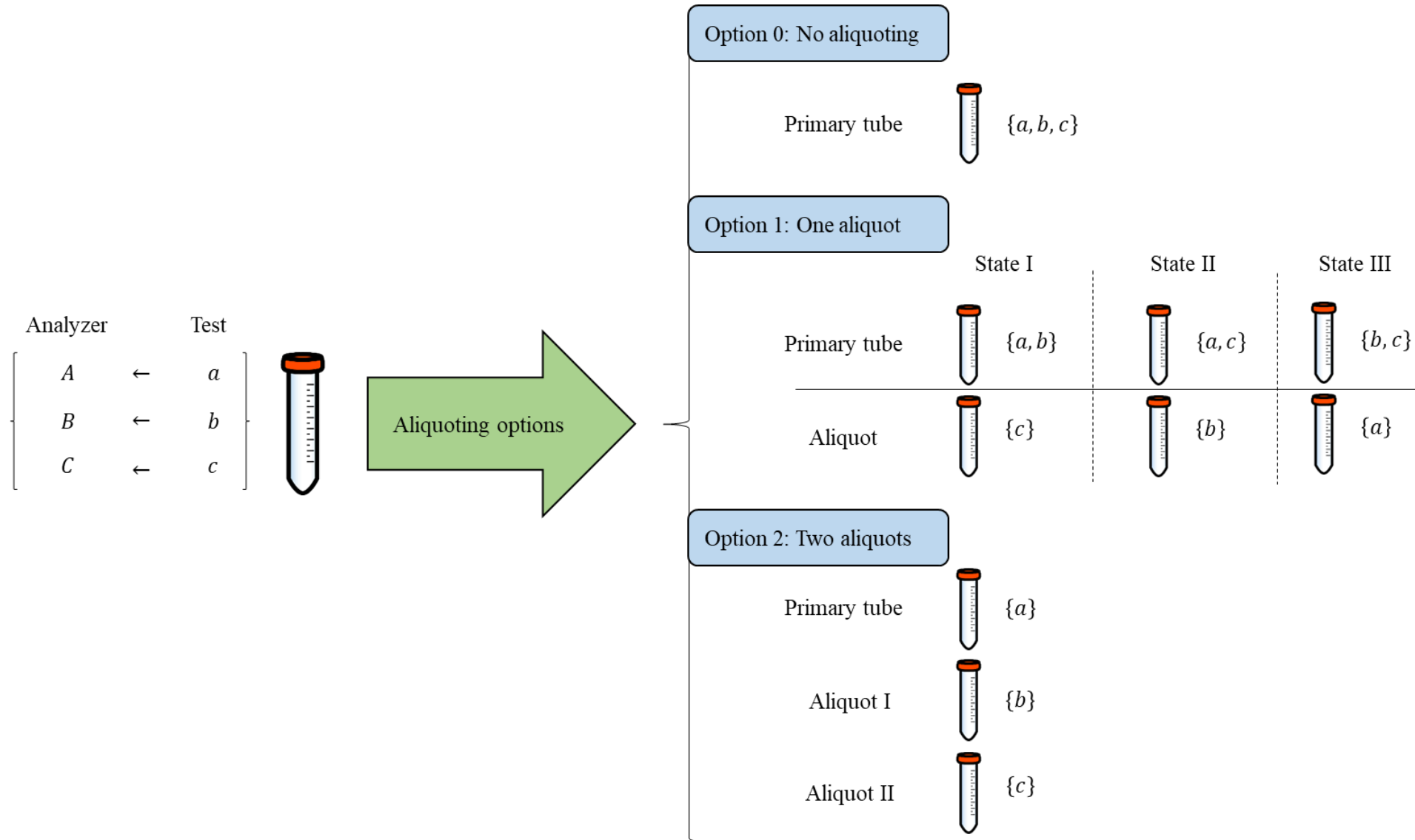
Aliquoting

-  **Simplifies the workflow** and **increases traceability** in laboratories
-  **Better scheduling**; e.g. deadline satisfaction
-  **Brings Extra costs** and **increases the number of tubes**
-  **Fixed policies** for current laboratories

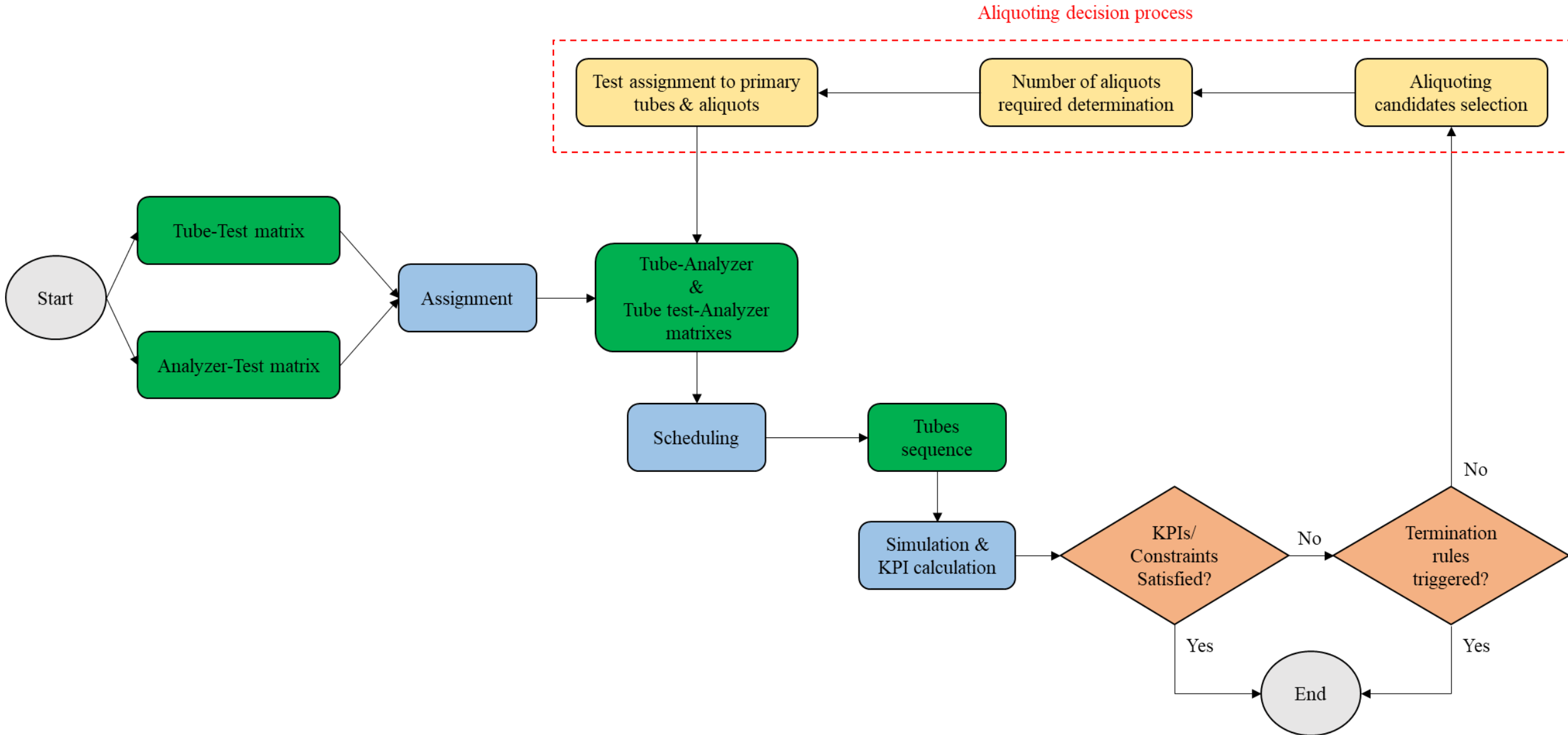
Challenges

-  Aliquoting alternatives
-  How many aliquots
-  Test assignment to aliquots

PROBLEM DEFINITION: ILLUSTRATIVE EXAMPLE



FIRST PROPOSED RESOLUTION APPROACH





SIMULATION MODELING

OF CLINICAL LABORATORY



CLINICAL LABORATORY SIMULATION MODELING

● Simulation type: Discrete-Event-Simulation

● Simulation software: FlexSim



● Customized simulation environment

❖ Customized library (SimuLab): 28 objects

❖ Customized flow items: Tube and Racks

❖ Input/output Tables

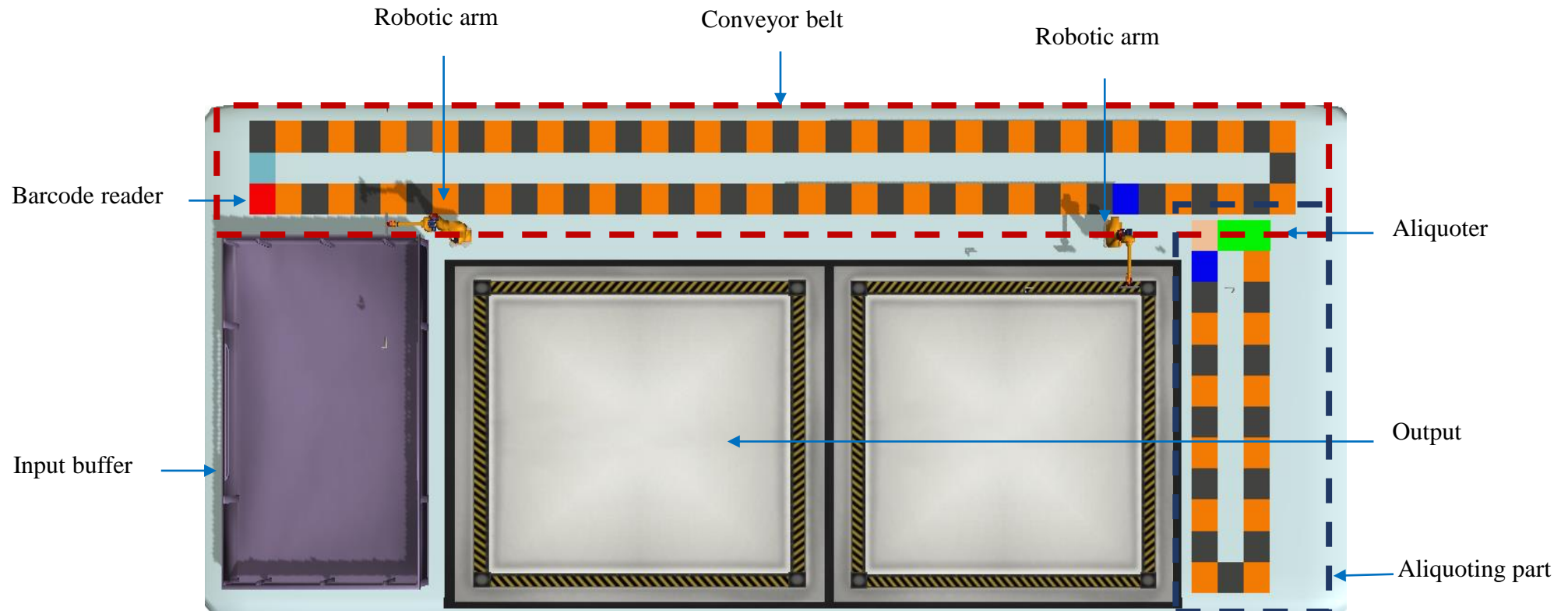
SimuLab

AU480	AU680
AU2700	AU5422
AU5432	AU5812
AU5822	AU5832
AU5842	DxC600
DxC800	DxI600
DxI800	DxC600i
DxC660i	DxC680i
Dx860i	DxC880i
General Analyze	Automate
Centrifuge	Tube Generator
Rack builder_Ce	Re_racking Des
Refrige	Refrigerator
Operator	Operator
Chair	Chair
Keyboard	Keyboard
Pillar	Pillar
Door	General Shape

(a) Tube
 (b) Centrifuge rack (10 tubes)
 (c) DxIs & DxCs rack (4 tubes)
 (d) AUs & DxCs rack (10 position)
 (e) Automate rack (50 position)

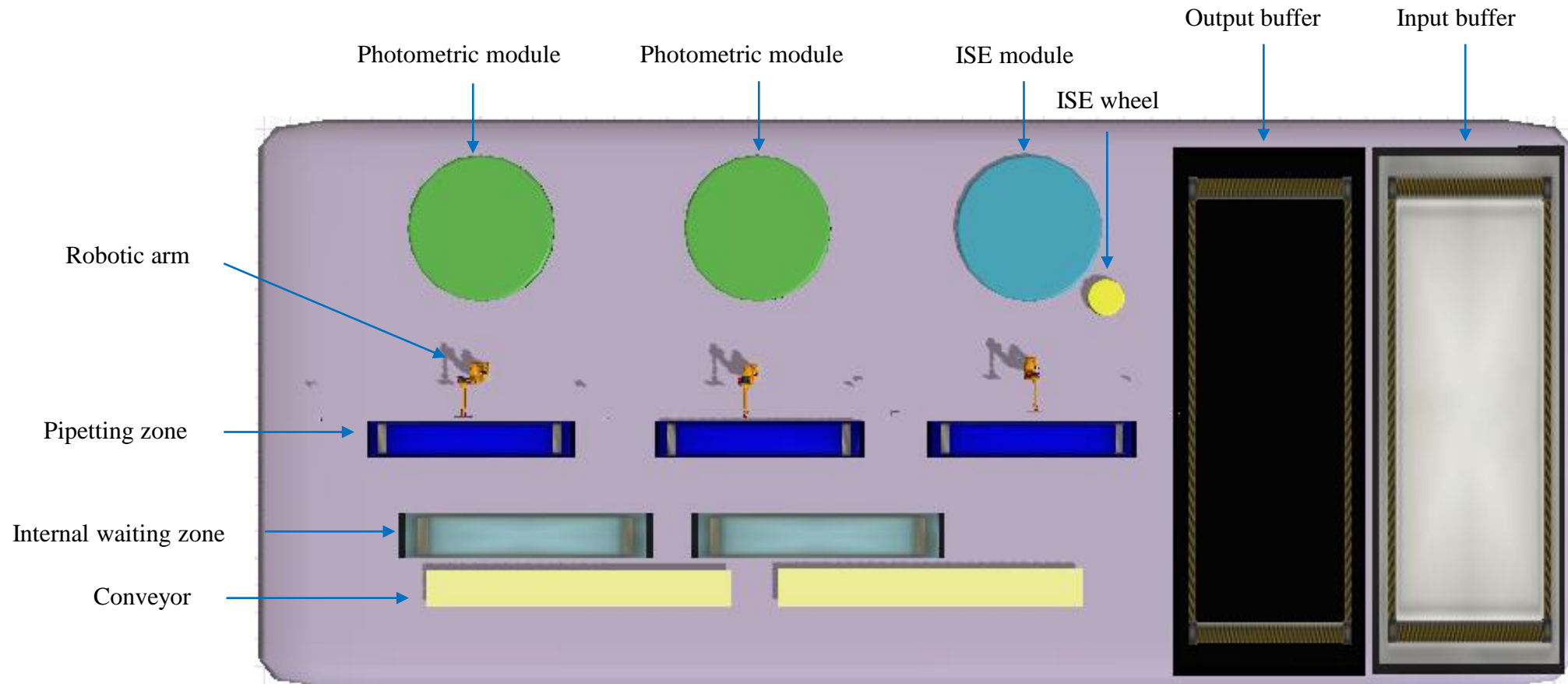
EXAMPLE OF A SIMULATED OBJECT

- Automate (Sorter with aliquoter)



EXAMPLE OF A SIMULATED OBJECT

AU5422 (Chemistry analyzer)





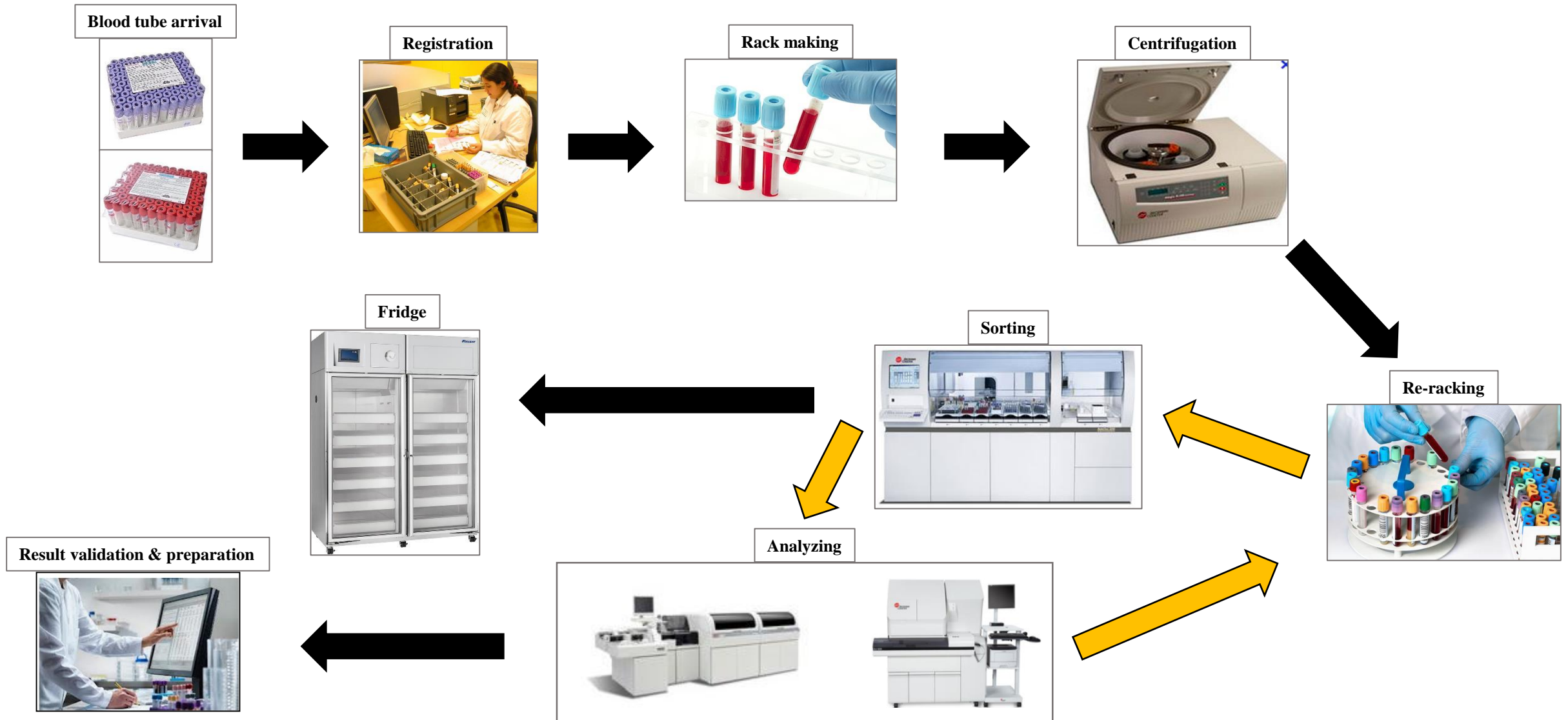
MAIN CHARACTERISTICS OF CLINICAL LABORATORY

- A **real-world system** with complicated machine environment
- Machines with **complicated operational attributes**
- **Several different flows** through the system
 - ▣ Tubes/Racks flow through the laboratory
 - ▣ Sample flow through the analyzers
 - ▣ Information (test result) flow through the system
- Dynamicity
- Stochasticity
- Batch processing

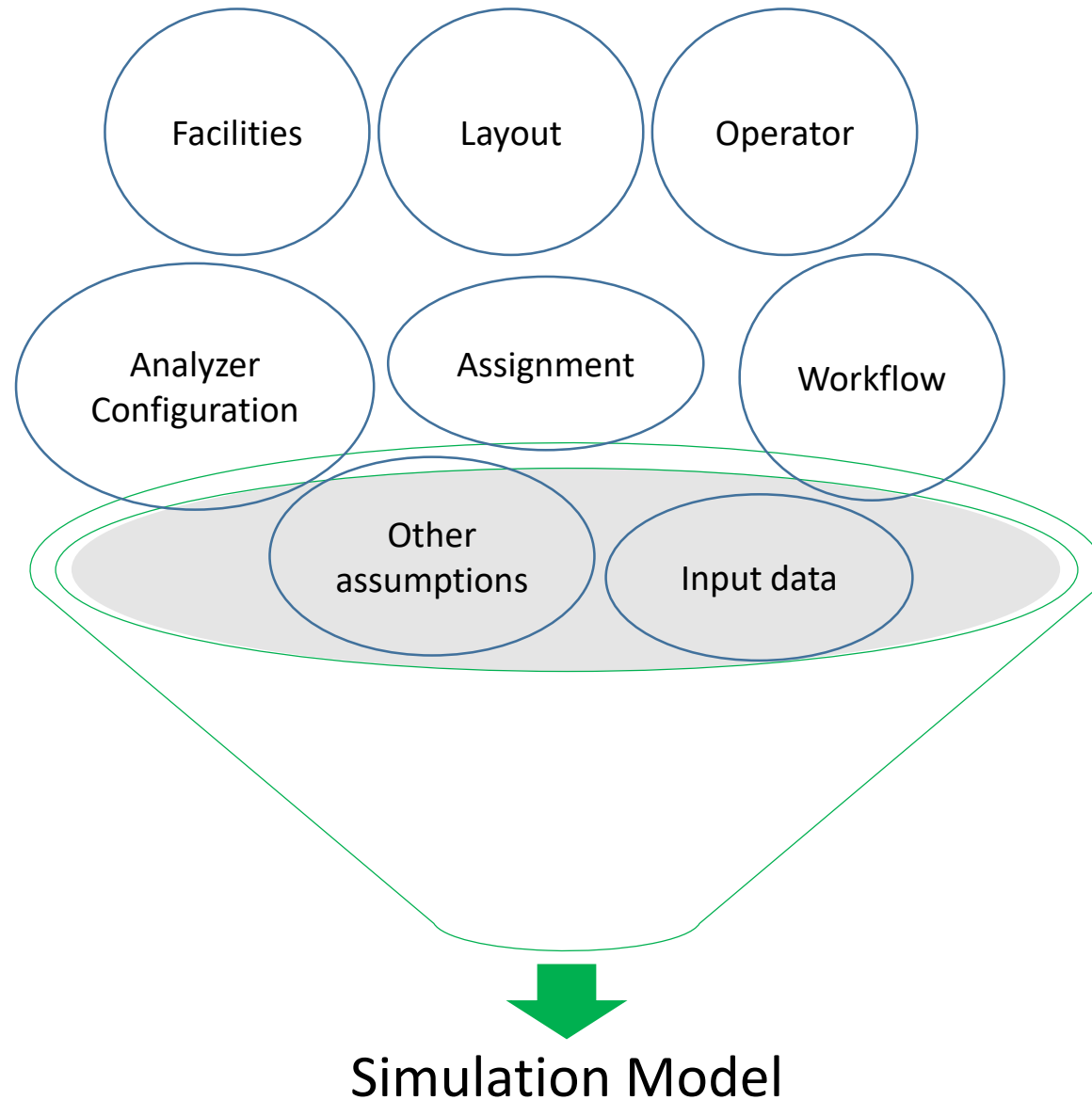
MAIN CHARACTERISTICS OF CLINICAL LABORATORY

- **Machine eligibility restriction** regarding the available reagent
- **Precedence constraints** between some tests of a tube for some tubes
- Aliquoting
- Backtracking or recirculation
- Tubes with different **priorities**: STAT or Routine
- **Operators** as transporters or task executers (in registration, validation, rack making)
- **Multiple objectives**
 - ▣ Turnaround Time (TAT) minimization
 - ▣ Throughput maximization

CASE STUDY: GENERAL WORKFLOW



SIMULATION MODELING INPUTS





KEY PERFORMANCE INDICATORS (KPIs)

- Turnaround time (TAT)
- Tube time in system (TIS)
- Throughput
- Resource utilization
- Tube/Test Tardiness
- Waiting times at queues

SIMULATION MODELING PROCEDURE

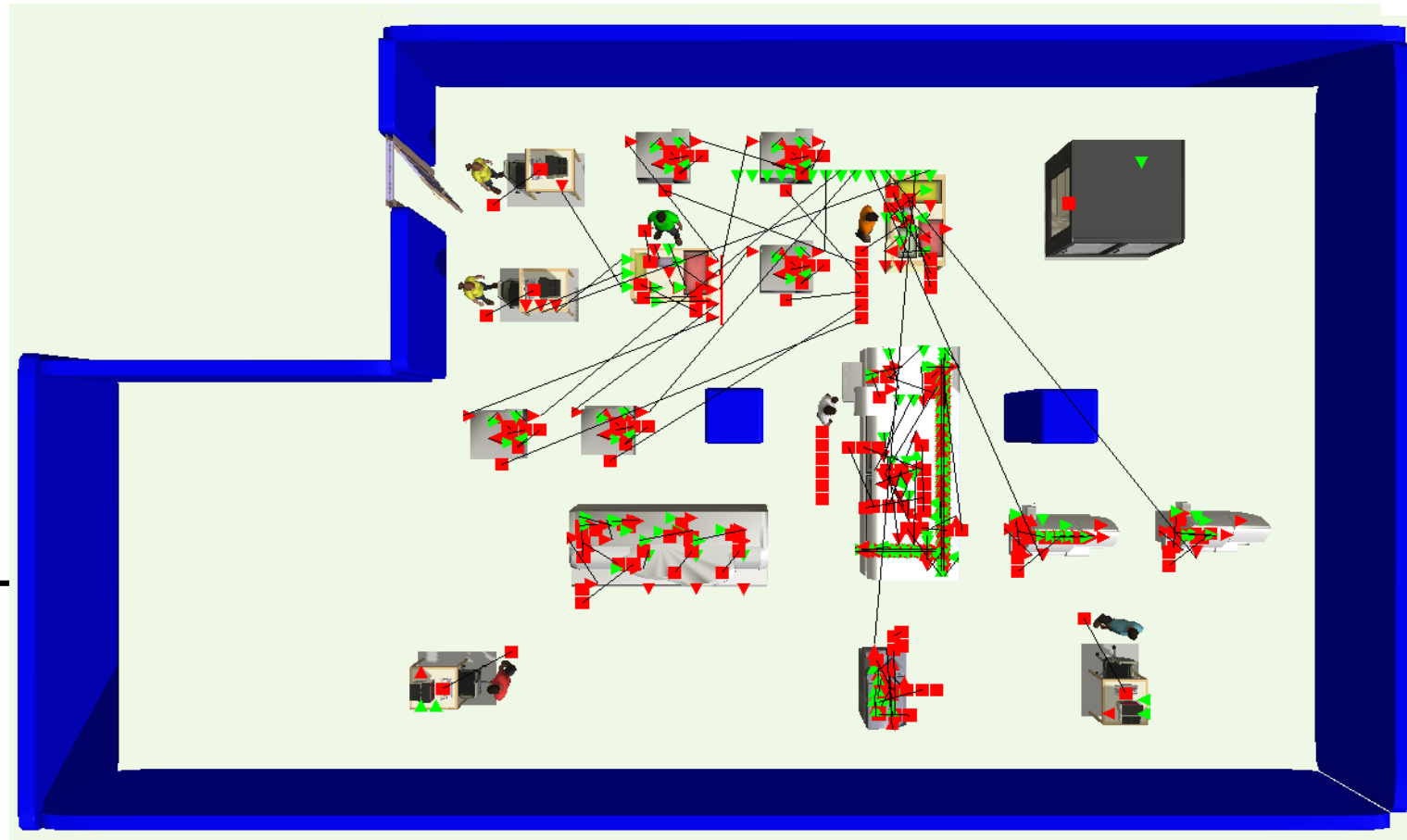
- 1 Create laboratory area
- 2 Add objects from 'SimuLab' library
- 3 Connect selected objects

□ Entities

- Tubes
- Racks
- Testing samples
- Tests result

Entrance

Wall



SIMULATION OUTPUTS

Customized output Tables + Standard FlexSim dashboard

Laboratory throughput

Average number of tests analyzed per hour	3052.65
Average number of tubes treated per hour	534.39

Test TAT from tube registration to test validation

Average TAT	84.47 min
Maximum TAT	250.65 min
Minimum TAT	23.28 min

Tube TAT from tube registration to test validation

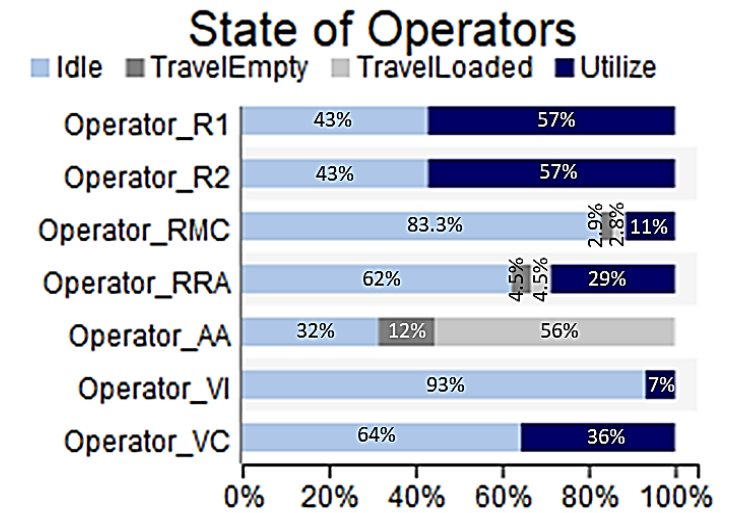
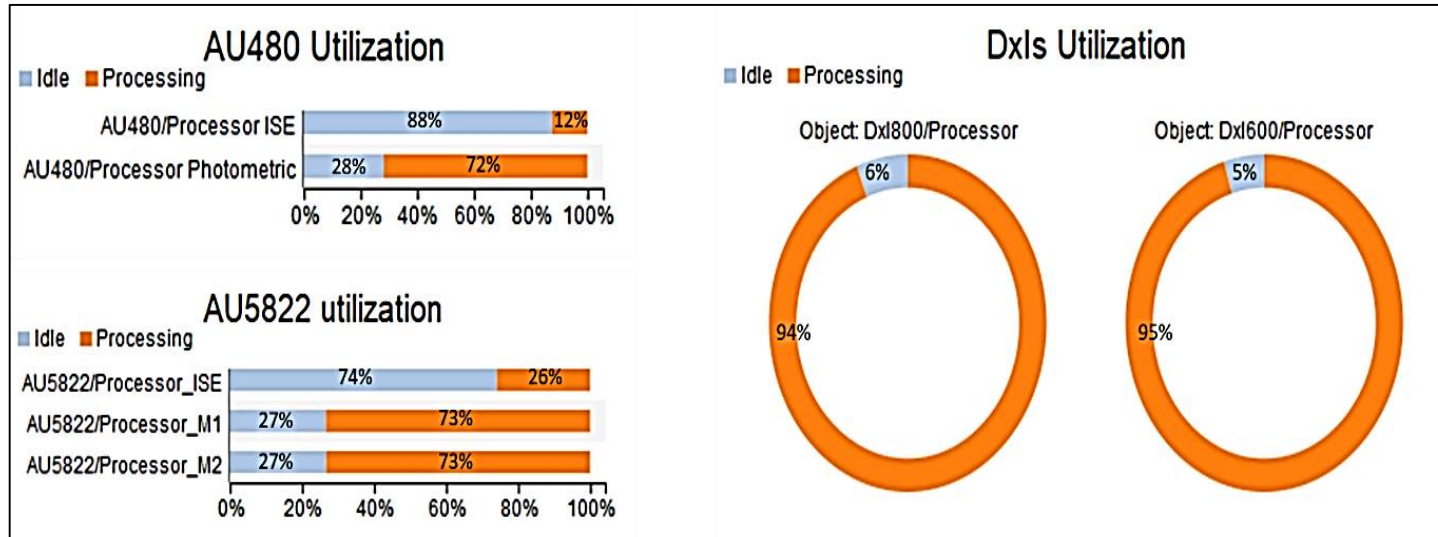
Average TAT	108.37 min
Maximum TAT	250.06 min
Minimum TAT	31.91 min

Tardy tubes

Total number of tardy tubes	202
Percentage of tardy tubes	5.25%
Number of tardy Immunology tubes	37
Number of tardy Chemistry tubes	0
Number of tardy Immunology-Chemistry tubes	165

SIMULATION OUTPUTS

Resource utilization



Waiting times

Staytime at different Queues

Object	Min	Max	Average
Tube Generator/Tubes Q	0.00	19230.00	9612.50
Rack builder_Centrifuge/Tube entry	0.00	36.18	1.67
Rack builder_Centrifuge/Output	0.00	4163.71	2032.06
Re_racking Desk/Entry point	0.00	60.93	10.49
Re_racking Desk/Output	0.00	396.44	107.47
Automate/Tubes_Q	0.75	247.39	142.10
Automate/Output	0.00	83.34	14.24
AU5822/Input buffer	0.00	0.00	0.00
AU480/Input buffer	0.00	348.89	29.43
Dxl800/Input buffer	0.00	105.10	14.62
Dxl600/Input buffer	0.00	11.29	0.22
Validation Console_I/Entry point	0.00	3.89	0.16
Validation Console_C/Entry point	0.00	21.42	0.91



Mismanagement in Personnel planning



CONCLUSION AND PERSPECTIVES



CONCLUSION AND CONTRIBUTIONS

- Comprehensive study on clinical laboratory optimization
 - ✦ System identification
 - ✦ Decision problems identification and definition
- An optimization framework for efficient decision making on CL design and planning
- Customized single and multi-objective mathematical models for
 - ✦ Machine selection problem
 - ✦ Analyzer configuration problem
 - ✦ Assignment problem
- Customized hybrid heuristic algorithm for clinical laboratory layout design problem
- Address and characterize the aliquoting problem as an optimization problem
- Customized simulation environment



PERSPECTIVES

- Clinical laboratory with automation line
- Optimizing the number of full-time employees
- Advanced optimization algorithms for multi-objectives problems
 - ▣ Pareto-based approaches
 - ▣ MCDM
- Evaluation on different benchmarks at different scales
- Simulation integration with optimization methods

PUBLICATIONS AND SCIENTIFIC PRODUCTIONS

- One published US patent entitled 'Intelligent handling of materials'

<https://patents.google.com/patent/WO2018111721A1/en>

- Two filed US patent entitled

- ✦ 'Laboratory instrument selection and configuration'

- ✦ 'System and method for clinical laboratory layout design'

- Two accepted full papers in international conferences

- ✦ Sohrab Faramarzi Oghani, El-Ghazali Talbi, Martin Bué, Eric Varlet. Optimization of analyzers configuration in a clinical laboratory: a mathematical model. *MOSIM'18*, Jun 2018, Toulouse, France.

- ✦ Sohrab Faramarzi Oghani, El-Ghazali Talbi, Martin Bué, Eric Varlet. A heuristic approach for standalone clinical laboratory layout design. *META'2018*, October 2018, Marrakesh, Morocco.

- One accepted and presented abstract entitled 'A mathematical model for machine selection problem in clinical laboratories' in OR2018 Conference in *Brussels*, Belgium.

Questions?

Thank You