Sustainable Mobility Program

Design of a large-scale biomass bulk terminal

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1. The research - Background

- Concern for sustainability boosts the use of renewable sources in energy sector.
- EU directives for the future (e.g. Renewable energy road map, Biomass action plan) show biomass and bio-energy will play one of the key roles.

The research – Background (cont.)

- The local supply can not meet the demand in the European Union, international import is necessary.
- In this context, a large-scale bulk import terminal dedicated to handle biomass is required.

The research - Context

- Time frame: 2020 onwards.
- Terminal throughput per year: 20-40 million ton/year.
- Seven biomass materials and products are chosen. The solid/liquid biomass ratio is 60/40 to 45/55.

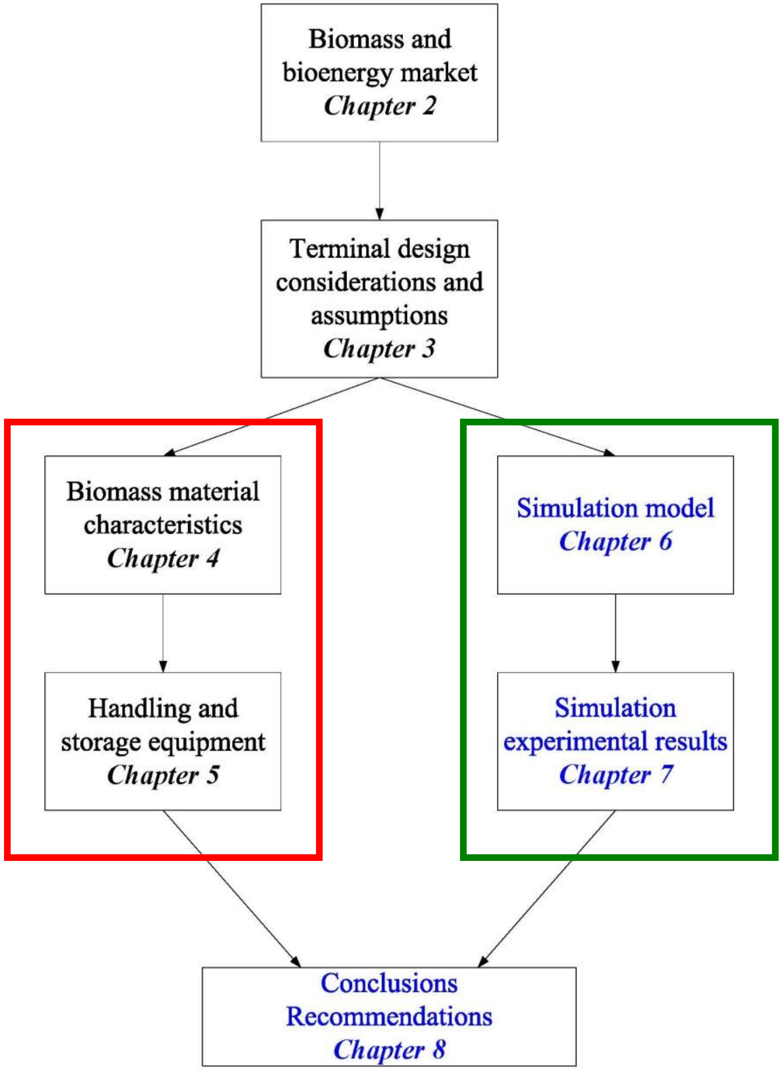
Wood pellets	Vegetable oils
Wood chips	Ethanol
Torrefied pellets	Biodiesel
	Pyrolysis oils

- The terminal should comply with possible sustainability certification in the future.

The research – The research questions

- *How important are biomass materials and products? What kind of scale can be expected in the future when biomass materials and products are imported into the European Union?*
- *How do the characteristics of biomass materials and products affect the terminal design and material handling?*

The research – Thesis outline



Two main themes:

1. Material properties and equipment
2. Simulation model

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2. Material properties

- To deploy suitable equipment and methods, the unique properties and the properties variations of the potential cargos need to be known and quantified.
- For liquid biomass, the properties crucial for handling and storage are documented. For solid biomass, the complete range of these properties is lacking. 1
- Experiments were carried out to obtain the important physical properties of solid biomass.

Material properties (cont.)

- 7 test materials: wood pellets, wood chips and torrefied pellets.

Material	Origin	Moisture Content (%)	Dimension (mm)
Wood pellets	Canada	<10	6 8 12 (diameter)
Wood chips	The Netherlands	35 ~ 45	0-20 0-40 0-100 (length)
Torrefied pellets*	The Netherlands	2 ~ 3	6 (diameter)

* Feedstock: poplar chips

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Material properties (cont.) – Solid Biomass

Table 1: Comparison of physical properties from wood pellets, wood chips, torrefied pellets, and coal.

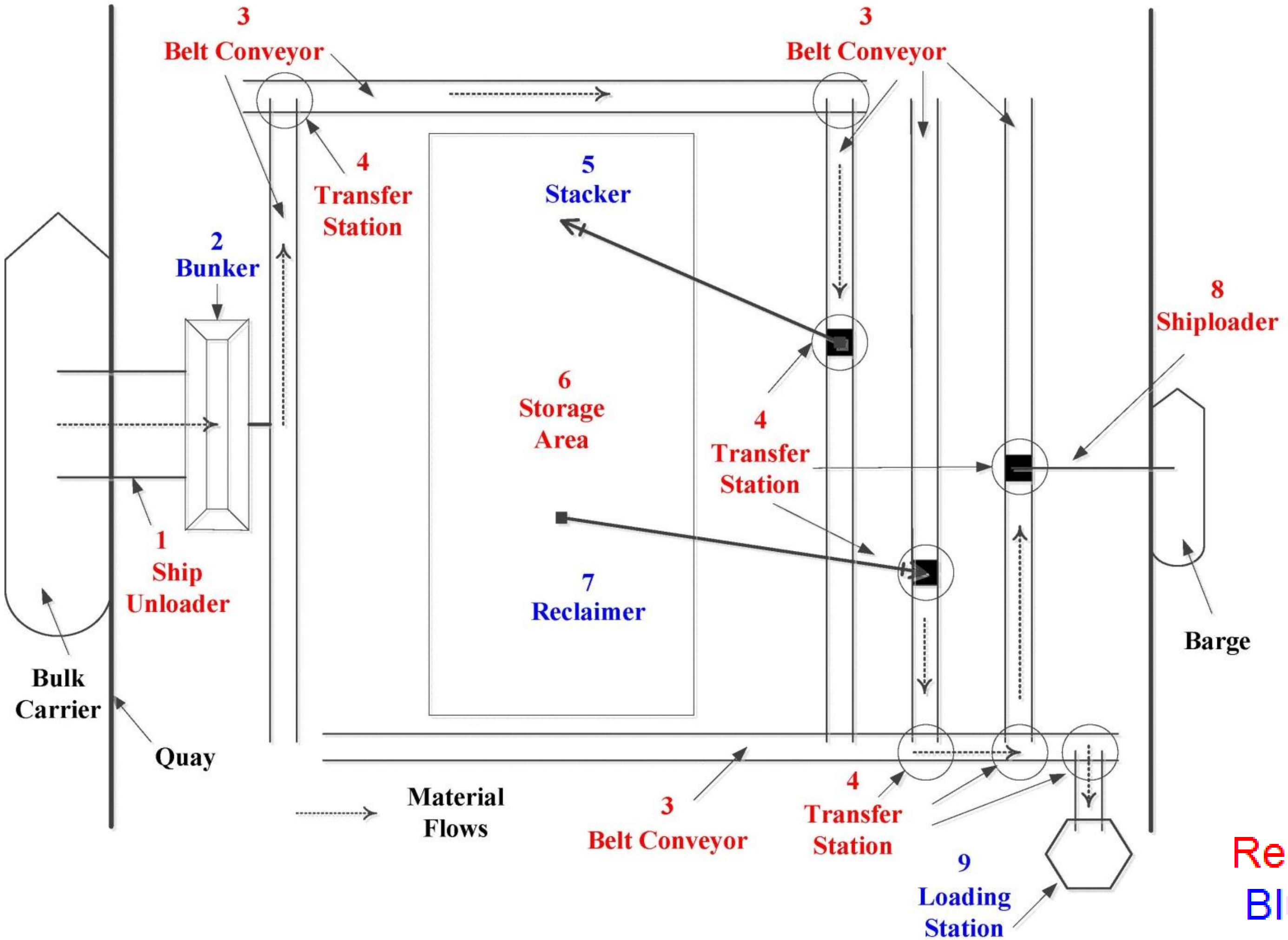
		Torrefied pellets	**Wood pellets**	**Wood chips**	**Coal**
	Energy Content (LHV) (GJ/ton)	8 - 21	16 - 18	14 - 17	30[a]
Physical Properties	Particle Density (kg/m^3)	1225 - 1251	1174 - 1820	N/A[b]	1100 - 1800
	Bulk Density (kg/m^3)	633 - 651	506 - 629	223 - 263	640 - 920
	Moisture Content (%)	4	8 - 11	42 - 49	15 - 65
	Angle of internal friction (○)	45	35 - 41	45 - 47	N/A
	Effective angle of internal friction (○)	48	40 - 43	48 - 53	55
	Angle of repose (○)	38 - 44	34 - 40	43 - 47	27-45
Handling equipment in contact with solid biomass materials and products	Wall friction angle (PE) (○)	12	9 - 11	15 - 19	10 - 15
	Wall friction angle (Concrete)(○)	29	29 - 32	32 - 36	30
	Wall friction angle (Mild Steel)(○)	15	16 - 17	25 - 29	24 - 34
	Wall friction angle (Stainless Steel)(○)	26	17 - 19	29 - 30	25 - 35

[a] UN Standard
[b] N/A = not applicable

Material properties (cont.)

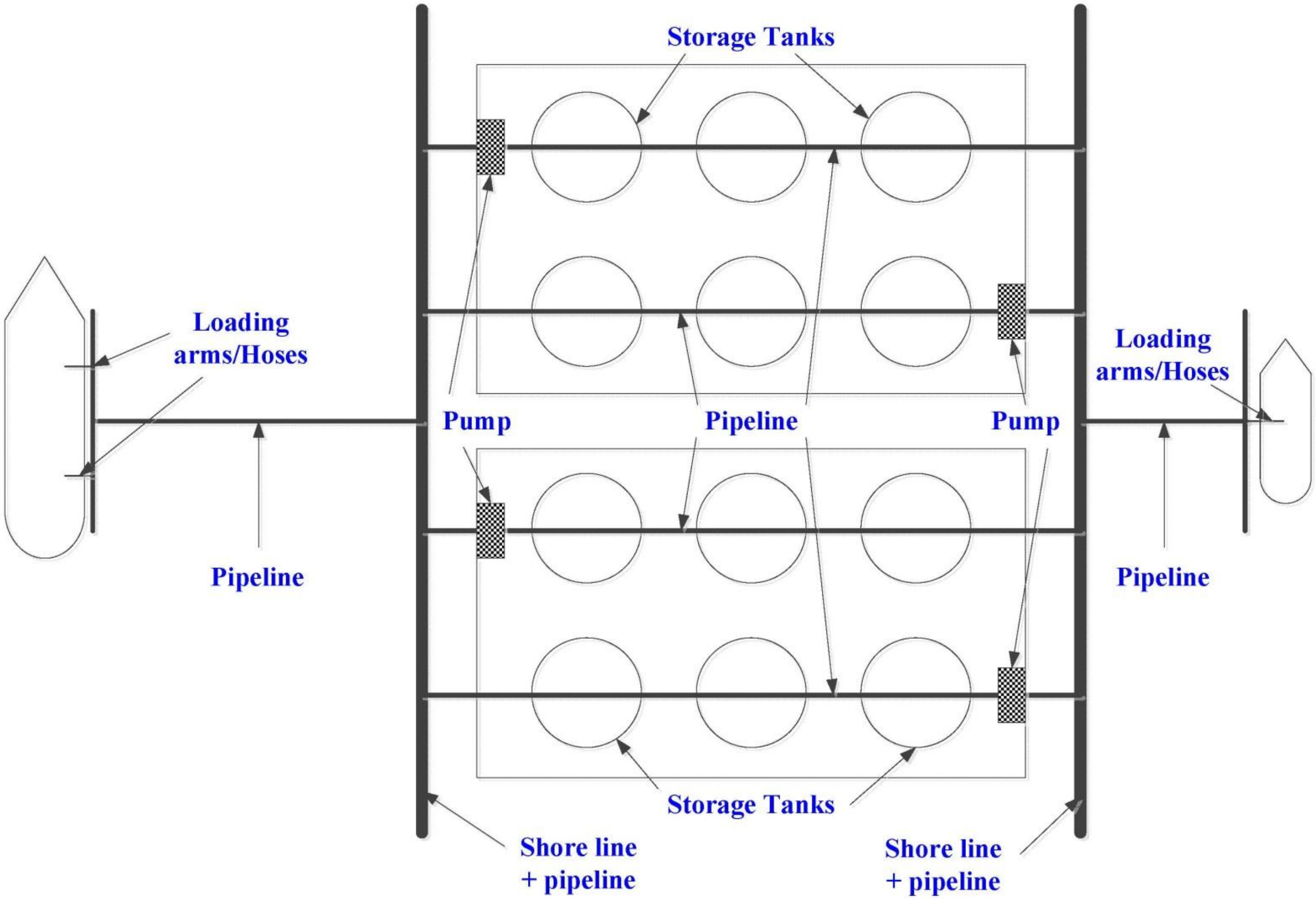
- No major difference between liquid biomass substances and commonly handled liquid bulk materials.
- Energy content of selected solid biomass can be 2 times lower than coal, bulk density can be 4 times lower. To achieve same energy content up to 8 times more volume is required.
- Differences between solid biomass and coal (bulk density, energy content, angle of repose, wall friction, effective angle of internal friction).

3. Equipment – Solid biomass



Red: different
Blue: similar

Equipment (cont.) – Liquid biomass



Equipment (cont.)

- Handling and storage equipment is mainly designed for commonly handled bulk materials (e.g. coal, iron ore, vegetable oils, biodiesel).
- To check if equipment can cope with biomass materials and products, compare material properties between biomass and commonly handled bulk materials.
- Majority of the equipment deployed at a terminal will need to be adjusted to cope with large scale solid biomass materials and products.

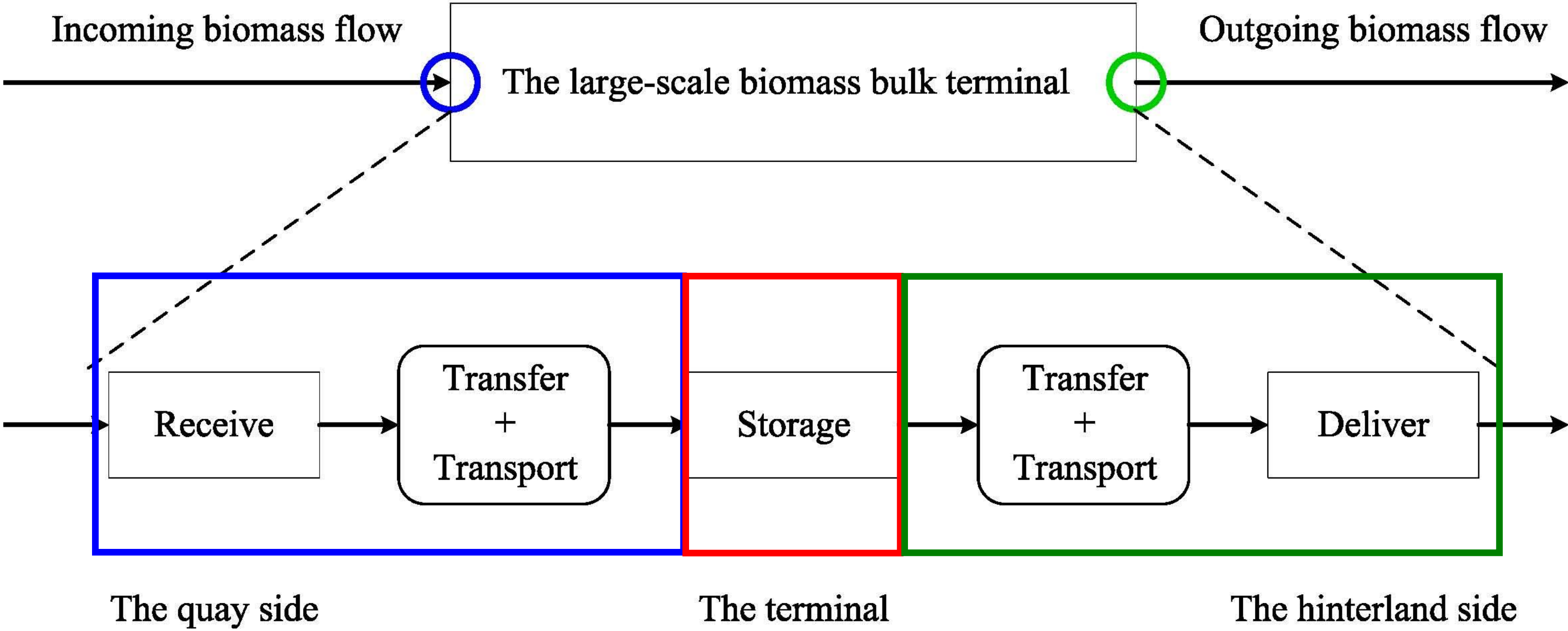
4. Simulation model

- Known:
  - Material properties
  - Types of equipment
  - Handling methods/processes

- Not known:
  - Vessel arrival pattern
  - Modal split (hinterland)
  - Numbers of equipment
  - Replenishment of the storage stocks

- Simulation:
  - Cope with stochastic effects
  - Sketch possible outcomes based on different design conditions and scenarios

Simulation model – structure



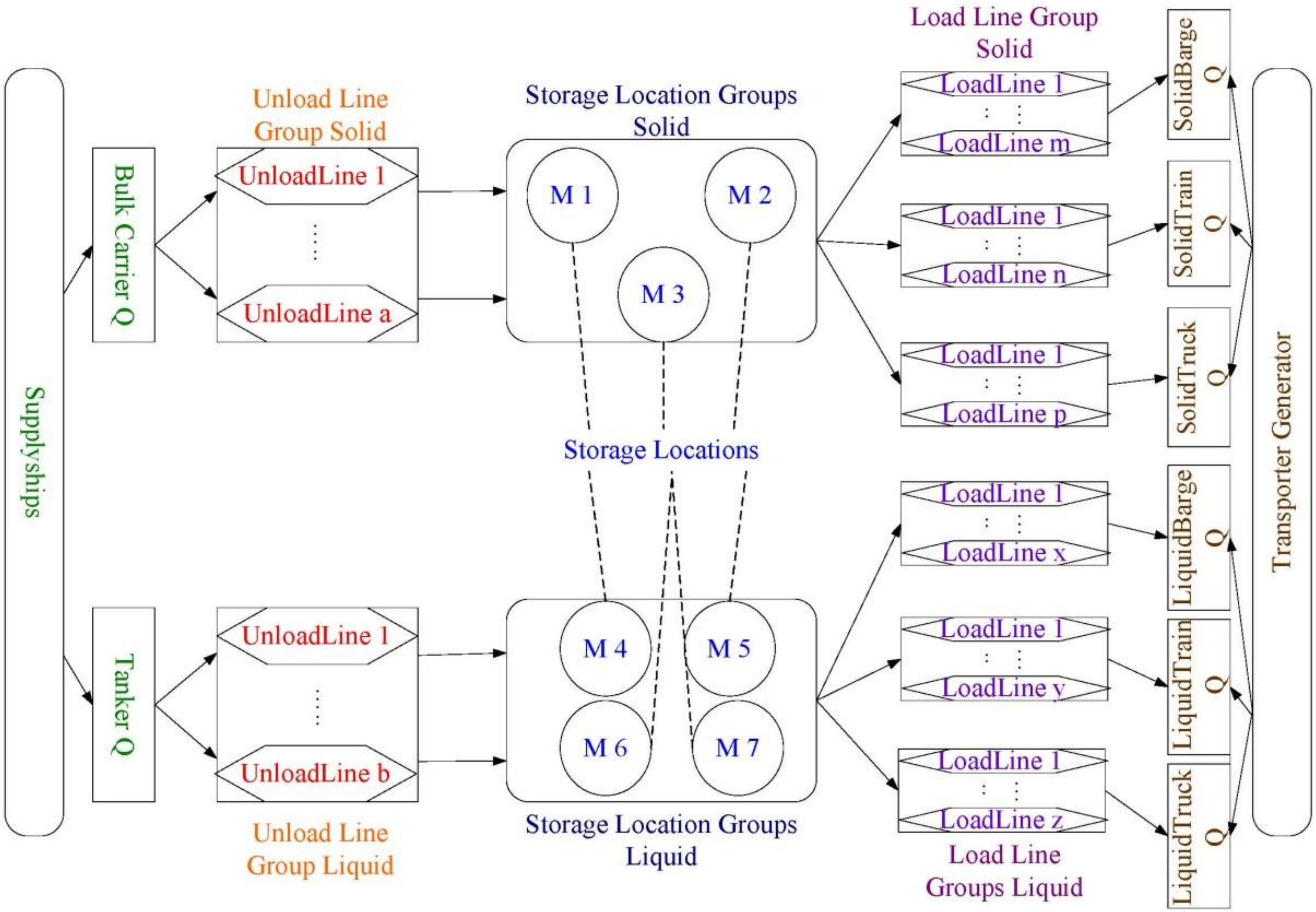
Simulation model – configuration of the terminal

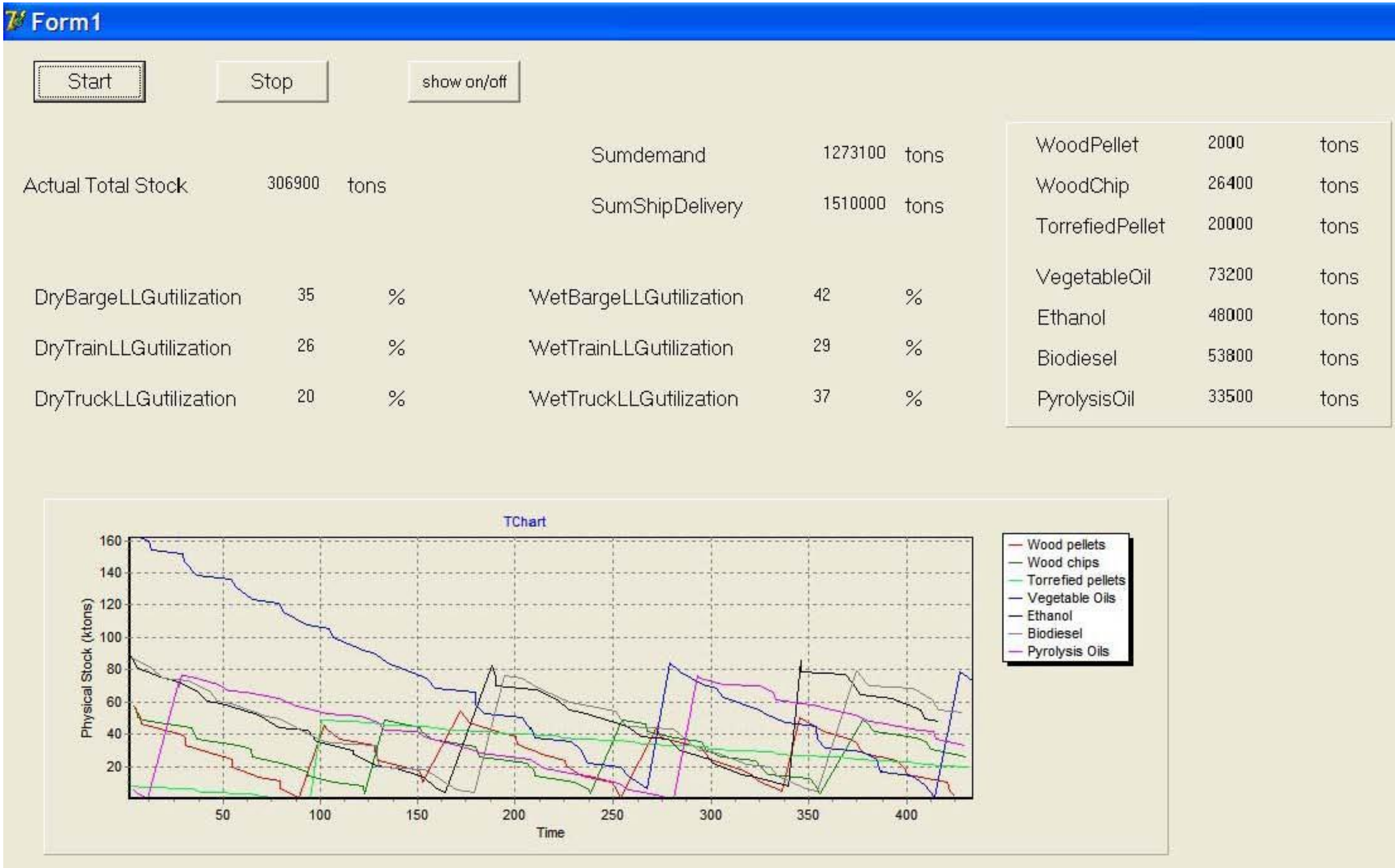
- Layout (size in terms of m^2)
- Equipment
  - Handling equipment and capacity (ton/hr)
  - Storage equipment and capacity (ton, m^{3})
- Operation control (e.g. storage stock level management)

Simulation model – Key Performance Indicators

- Waiting time of ocean going vessels and hinterland transporter (average, max, 95% percentile, pattern).
- Waiting queue length of ocean going vessels and hinterland transporter (average, max).
- Utilization rate of equipment.
- Material Storage time and storage capacity.

Simulation model – structure




Form1
Start
Stop
show on/off
Actual Total Stock 306900 tons
Sumdemand 1273100 tons
SumShipDelivery 1510000 tons
WoodPellet 2000 tons
WoodChip 26400 tons
TorrefiedPellet 20000 tons
VegetableOil 73200 tons
Ethanol 48000 tons
Biodiesel 53800 tons
PyrolysisOil 33500 tons
DryBargeLLGutilization 35 %
DryTrainLLGutilization 26 %
DryTruckLLGutilization 20 %
WetBargeLLGutilization 42 %
WetTrainLLGutilization 29 %
WetTruckLLGutilization 37 %
TChart
Physical Stock (ktons)
Time
Wood pellets
Wood chips
Torrefied pellets
Vegetable Oils
Ethanol
Biodiesel
Pyrolysis Oils

Simulation model – experiment setup

Class	DWT (tons)
Bulk Carrier Panamax	60,000
Tanker Panamax	70,000
Bulk Carrier Handymax	40,000
Tanker Handymax	40,000
Bulk Carrier Capesize	100,000
Tanker Suezmax	150,000

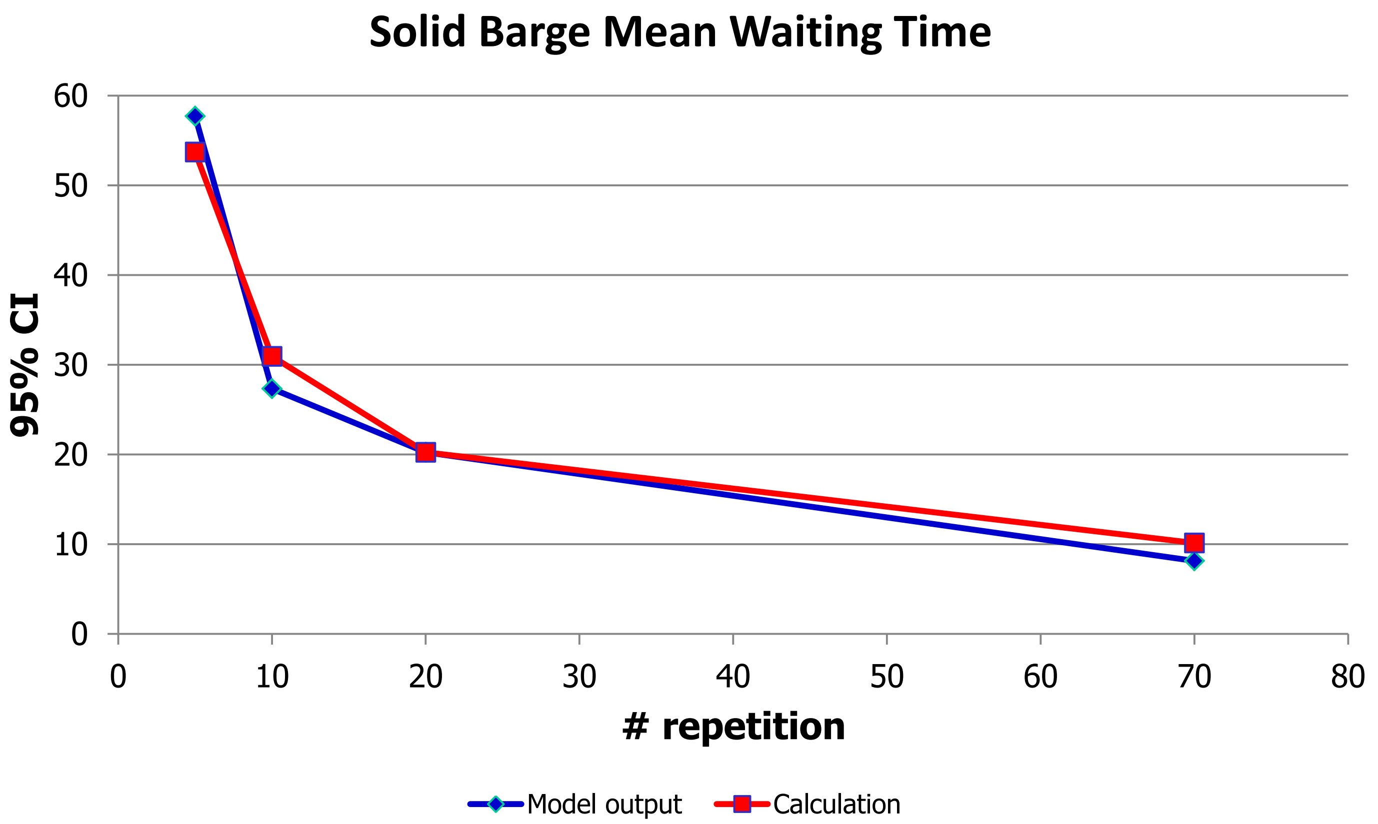
- Solid/Liquid ratio: 60/40.
- Number of unloading points: 2
- Working hours per year: 8760 hours.

$$CI = \frac{SD * t_{n-1,\alpha/2}}{\sqrt{n}}$$

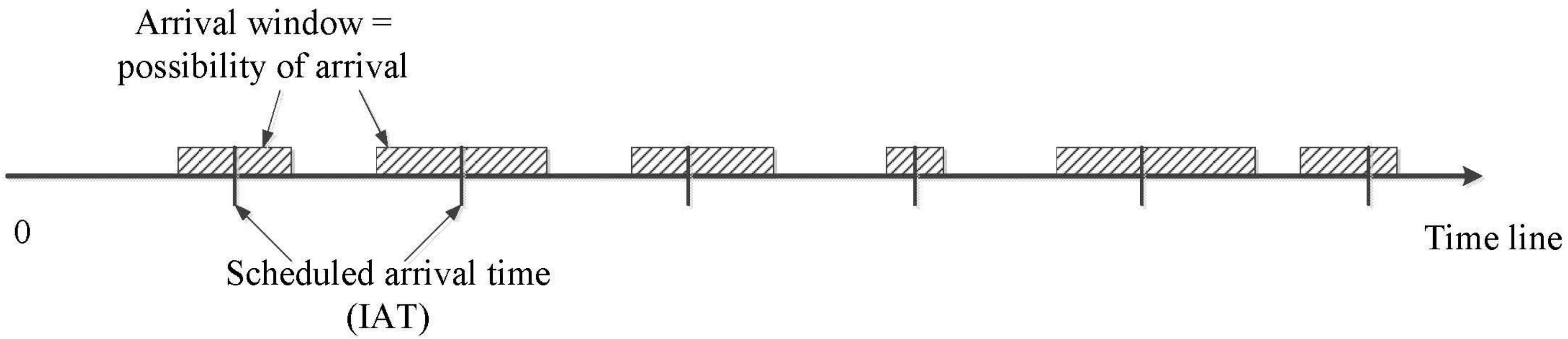
- CI: confidence interval; SD: standard deviation; n: number of repetitions; α: significance level.

Simulation model – experiment setup (cont.)

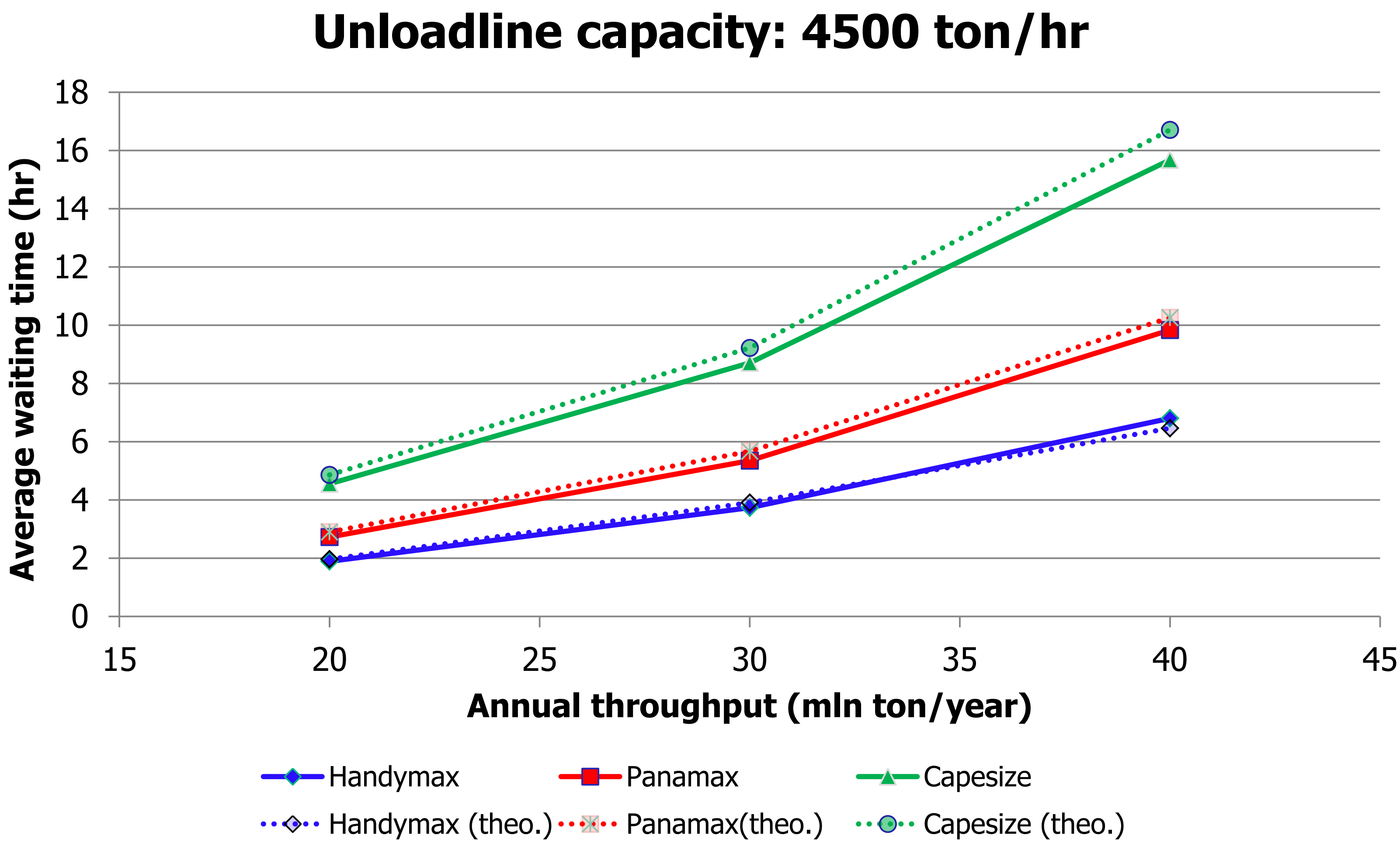
- Number of repetitions: 20 times.



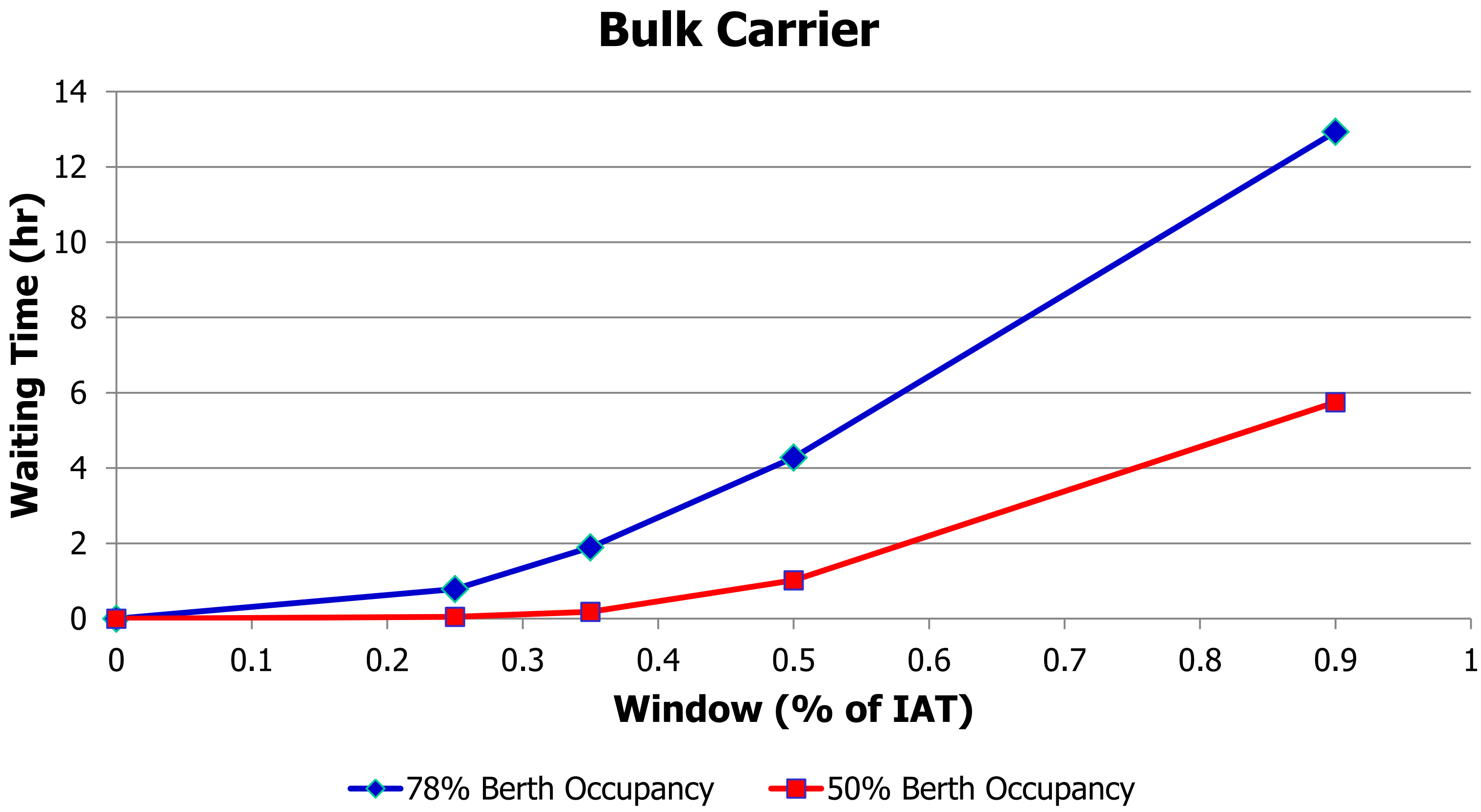
Simulation model – experiment setup (cont.)



Simulation model – initial results (M/D/1 queue)(Bulk Carrier)



Simulation model – initial results (cont.) (uniform arrival)



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5. Publications and future planning

Publications

[1] M. R. Wu, D. L. Schott, and G. Lodewijks, "Possibility of a large-scale biomass bulk terminal in the Hamburg-Le Havre region," in 16^{th} *European Biomass Conference & Exhibition*, (Valencia, Spain), ETA Renewable Energies, 2-6 June 2008.

[2] M. R. Wu, D. L. Schott, and G. Lodewijks, "On the potential for a large-scale biomass bulk terminal in the West European region," in *Selected paper for the* 10^{th} *International TRAIL Congress*, pp. 255–282, Rotterdam, the Netherlands: TRAIL research school, 14-15 October 2008. ISBN: 978-90-5584-112-7.

[3] M. R. Wu, D. L. Schott, and G. Lodewijks, "Properties and handling equipment of solid biomass as feedstock for bio-energy applications," in *Bulk Solids India 2010*, (Mumbai, India), 2-3 March 2010.

[4] M. R. Wu, J. A. Ottjes, D. L. Schott, and G. Lodewijks, "Design of a large-scale biomass bulk terminal aided by a simulation model," in *Bulk Solids Europe 2010*, (Glasgow, Scotland), Vogel Business Media, 9-10 September 2010.

[5] M. R. Wu, D. L. Schott, and G. Lodewijks, "Significant factors for the design of a large-scale biomass bulk terminal - impacts of future sustainability certification systems," in *11th TRAIL Congress 2010*, (Rotterdam, the Netherlands), 23-24 November 2010.

[6] M. R. Wu, D. L. Schott, and G. Lodewijks, "Physical properties of solid biomass," *Biomass and Bioenergy*, vol. 35, pp. 2093–2105, 2011.

[7] M. R. Wu, J. A. Ottjes, D. L. Schott, and G. Lodewijks, "A simulation model for the design of a large-scale biomass bulk terminal," *Bulk Solids Handling*, vol. 31, no. 1, pp. 32–37, 2011.

[8] M. R. Wu, J. A. Ottjes, D. L. Schott, and G. Lodewijks, "Material handling and logistic flows at a large-scale biomass bulk terminal," in 19^{th} *European Biomass Conference & Exhibition*, (Berlin, Germany), 6-10 June 2011.

Table 4.8: Overview of decisive handling properties for vegetable oils, ethanol, biodiesel, and pyrolysis oil, based on Table 4.3 to Table 4.6.

Material / Properties		**Vegetable oils**	**Ethanol**	**Biodiesel**	**Pyrolysis oil**
Physical properties	Density (kg/m^3)	910-923	791.5 (at 20°C, max)	850-900 (at 15-20°C)	1110-1300
	Water content (wt%)	depends on situation[1]	0.3 or 1.0 (by vol%)	0.05 (max)	15-30
	Viscosity at 40°C(mm^2/s)	24-65 (at 27-40°C)	N/D[2]	1.9-6.0	10-220
	Flash point (°C)	228-346	N/D	93-101 (min)	40-70 or >100[3]
	Cloud point (°C)	-10-33	N/D	N/D or report[4]	no clouding phenomenon is observed, which may be due to the dark color of pyrolysis oil
	Pour point (°C)	-18--9	N/D	N/D	-36--9
Handling equipment in contact with liquid biomass substances	pH	N/D	6.5-9.0	N/D	2-4
	Acid value (mg KOH/g)	N/D	0.007 (as % (m/m), max)	0.5-0.8	50-100
	Oxidation stability (at 110°C)(hour)	N/D	N/D	3-6 (min)	N/D[5]
	Copper corrosion (3 hours at 50°C)	N/D	N/D	1-3 (max)	N/D

1 Oil seeds are natural products so the water content can vary. After extraction of the oil residual water is removed to specs by refining. Water content can increase during storage.

2 not defined

3 refer to Table 4.6

4 refer to Table 4.5

5 Instability shown as: 1. Evaporation of volatile components under air. Possible reactions with air. 2. Slow increase in viscotyi and phase-separation. 3. Fast increase in viscosity/polymerisation and phase-separation by heating. [28]

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Test materials

Experiments

Experiments (cont.)

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