Chapter 5: Case 2-2 - Ulsan to Busan

5.1 Overview

Parameter	Value
Case ID	case_2_ulsan
Storage at Busan	**No**
Route	Ulsan to Busan
Distance	25 nautical miles
Travel Time (one-way)	1.67 hours (25 nm / 15 knots)
Bunker Volume per Call	5,000 m3
Optimal Shuttle Size	**5,000 m3**

5.2 Cycle Time Calculation

5.2.1 Formula (Case 2 - Direct Supply)

Same formula as Case 2-1, but with shorter travel time:

```
Vessels_per_Trip = floor(Shuttle_Size / Bunker_Volume)

Cycle_Duration = Shore_Loading + Travel_Out + Travel_Return + Port_Entry_Exit
               + (Vessels_per_Trip × (Movement + Setup + Pumping))

where:
  Shore_Loading = Shuttle_Size / 1500
  Travel_Out = 1.67 hours (25 nm / 15 knots)
  Travel_Return = 1.67 hours
  Port_Entry_Exit = 2.0 hours
  Per_Vessel = 1.0 + 2.0 + 5.0 = 8.0 hours
```

5.2.2 Example: 5,000 m3 Shuttle (Optimal)

Step 1: Vessels per Trip

```
Vessels_per_Trip = floor(5000 / 5000) = 1 vessel
```

Step 2: Fixed Components

```
Shore_Loading = 5000 / 1500 = 3.3333 hours
Travel_Out = 1.67 hours
Travel_Return = 1.67 hours
Port_Entry_Exit = 2.0 hours

Fixed_Time = 3.3333 + 1.67 + 1.67 + 2.0 = 8.6733 hours
```

Step 3: Per-Vessel Components

```
Total_Vessel_Time = 1 vessel × 8.0 hours = 8.0 hours
```

Step 4: Total Cycle Duration

```
Cycle_Duration = 8.6733 + 8.0 = 16.6733 hours
```

CSV Verification: `Cycle_Duration_hr = 16.6733` [PASS]

5.2.3 Example: 2,500 m3 Shuttle

Step 1: Vessels per Trip

```
Vessels_per_Trip = floor(2500 / 5000) = 0 vessels
→ Treated as 1 vessel (partial delivery)
Note: Trips_per_Call = 2 (two trips to complete one bunkering call)
```

Step 2: Fixed Components

```
Shore_Loading = 2500 / 1500 = 1.6667 hours
Travel_Out = 1.67 hours
Travel_Return = 1.67 hours
Port_Entry_Exit = 2.0 hours

Fixed_Time = 1.6667 + 1.67 + 1.67 + 2.0 = 7.0067 hours
```

Step 3: Per-Vessel Components

```
Total_Vessel_Time = 1 × 8.0 hours = 8.0 hours
```

Step 4: Total Cycle Duration

```
Cycle_Duration = 7.0067 + 8.0 = 15.0067 hours
```

CSV Verification: `Cycle_Duration_hr = 15.0067` [PASS]

5.2.4 Example: 10,000 m3 Shuttle

Step 1: Vessels per Trip

```
Vessels_per_Trip = floor(10000 / 5000) = 2 vessels
```

Step 2: Fixed Components

```
Shore_Loading = 10000 / 1500 = 6.6667 hours
Travel_Out = 1.67 hours
Travel_Return = 1.67 hours
Port_Entry_Exit = 2.0 hours

Fixed_Time = 6.6667 + 1.67 + 1.67 + 2.0 = 12.0067 hours
```

Step 3: Per-Vessel Components

```
Total_Vessel_Time = 2 vessels × 8.0 hours = 16.0 hours
```

Step 4: Total Cycle Duration

`Cycle_Duration = 12.0067 + 16.0 = 28.0067 hours`

CSV Verification: `Cycle_Duration_hr = 28.0067` [PASS]

5.3 Annual Capacity Calculation

5.3.1 Verification Table

Shuttle (m3)	Vessels/Trip	Cycle (hr)	Annual Cycles	Ships/Year	CSV Match
2,500	1	15.01	533.10	266.55	[PASS]
5,000	1	16.67	479.81	479.81	[PASS]
10,000	2	28.01	285.65	571.29	[PASS]

5.4 Cost Verification

5.4.1 Shuttle CAPEX

Shuttle (m3)	CAPEX	Annualized CAPEX/yr
2,500	$7,761,316	$716,345
5,000	$13,051,896	$1,204,496
10,000	$21,951,652	$2,026,087

5.5 Shuttle Size Comparison

5.5.1 Comparison Table (1000 m3/h Pump)

Metric	2,500 m3	5,000 m3	10,000 m3
NPC Total	$487.48M	**$402.37M**	$495.93M
LCOAmmonia	$2.07/ton	**$1.71/ton**	$2.10/ton
Cycle Duration	15.01 hr	16.67 hr	28.01 hr
Vessels per Trip	1	1	2
Annual Cycles	533.10	479.81	285.65
Ships per Year	266.55	479.81	571.29
Time Utilization	100%	100%	100%

5.5.2 Cost Breakdown Comparison

Cost Component	2,500 m3	5,000 m3	10,000 m3
Annualized Shuttle CAPEX	$193.69M	$184.94M	$264.88M
Annualized Bunkering CAPEX	$13.81M	$10.09M	$11.81M
Shuttle Fixed OPEX	$104.93M	$100.20M	$143.51M
Bunkering Fixed OPEX	$7.48M	$5.47M	$6.40M
Shuttle Variable OPEX	$155.06M	$89.16M	$56.82M
Bunkering Variable OPEX	$12.51M	$12.51M	$12.51M
NPC Total	**$487.48M**	**$402.37M**	**$495.93M**

5.5.3 Why 5,000 m3 is Optimal

1. **Perfect match**: 5,000 m3 shuttle = 5,000 m3 bunker demand per call
2. **Single trip efficiency**: No wasted capacity, no multiple trips
3. **Short distance advantage**: 1.67 hr travel offsets smaller shuttle CAPEX benefit
4. **Lower variable OPEX**: $89.16M vs $155.06M (2,500) or $56.82M (10,000)

The 2,500 m3 shuttle requires 2 trips per call, doubling travel time impact. The 10,000 m3 shuttle has higher CAPEX and longer cycle time (28 hr) with diminishing returns.

5.6 Full Scenario Results

Shuttle (m3)	NPC (M)$\vert LCO(/ton)$	Cycle (hr)	Vessels/Trip	Utilization	
2,500	487.48	2.07	15.01	1	100%
5,000	**402.37**	**1.71**	**16.67**	**1**	100%
10,000	495.93	2.10	28.01	2	100%
15,000	592.93	2.52	39.34	3	100%
20,000	697.25	2.96	50.67	4	100%
25,000	796.83	3.38	62.01	5	100%
30,000	888.32	3.77	73.34	6	100%
35,000	980.81	4.16	84.67	7	100%
40,000	1068.50	4.53	96.01	8	100%
45,000	1151.88	4.89	107.34	9	100%
50,000	1242.02	5.27	118.67	10	100%

5.7 Comparison with Case 2-1 (Yeosu)

Metric	Case 2-1 (Yeosu)	Case 2-2 (Ulsan)	Difference
Distance	86 nm	25 nm	-71%
Travel Time	5.73 hr	1.67 hr	-71%
Optimal Shuttle	10,000 m3	5,000 m3	-50%
Optimal NPC	$747.18M	$402.37M	-46%
Optimal LCO	$3.17/ton	$1.71/ton	-46%

Key Insight: Shorter distance (Ulsan) enables smaller, more efficient shuttles and significantly lower costs.

5.8 Verification Summary

Item	Expected	CSV Result	Status
Optimal Shuttle	5,000 m3	5,000 m3 (min NPC)	[PASS]
Cycle Time (2500)	15.0067 hr	15.0067 hr	[PASS]
Cycle Time (5000)	16.6733 hr	16.6733 hr	[PASS]
Cycle Time (10000)	28.0067 hr	28.0067 hr	[PASS]
Vessels/Trip (5000)	1	1.0	[PASS]
Annuity Factor	10.8355	10.8355	[PASS]
NPC (5000)	~$402M	$402.37M	[PASS]
LCO (5000)	~$1.71/ton	$1.71/ton	[PASS]