ANALYSIS AND SIZING OF A COAL EXPORT SYSTEM THROUGH SIMULATION

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ABSTRACT

A coal export terminal aims to handle up to 40 million ton per annum (Mtpa) of mineral coal. The product will be transported by rail from a mine to the terminal located in Nakala, and then exported by ship. The project is scheduled in 3 phases, according to the production capacity: 15, 25 and 40 Mtpa. In order to perform the system sizing for each phase, a simulation discrete event simulation model was developed, so that results such as queue times and demurrage costs could be analyzed. The simulation model considers the arrival of trains, the stockyard and equipment dynamics and the export system. Several layouts were developed and simulated, varying parameters such as train capacity, stockyard size, number of berths, equipment rate and demand. Decisions related to the best layout configuration for each phase involves the previous or/and the subsequent phase, as well as operational and capital expenditure. The use of simulation methodology has succeeded in providing useful information for the system assessment.

Keywords: coal terminal, discrete event simulation, project of ports and harbour.

INTRODUCTION

The assessment of terminals has been a major issue among mining companies, which deal with the extraction, processing, storage and transportation of its products, resulting in a complex multimodal transportation. In this context, bulk material handling systems have a major impact on the transportation performance, also affecting demurrage costs.
In Mozambique, a mining company aims to handle up to 40 Mtpa of three types of coal, which will be transported by rail from the mine to a coal terminal in the city of Nakala, locate in the province of Nampula (Figure 1).

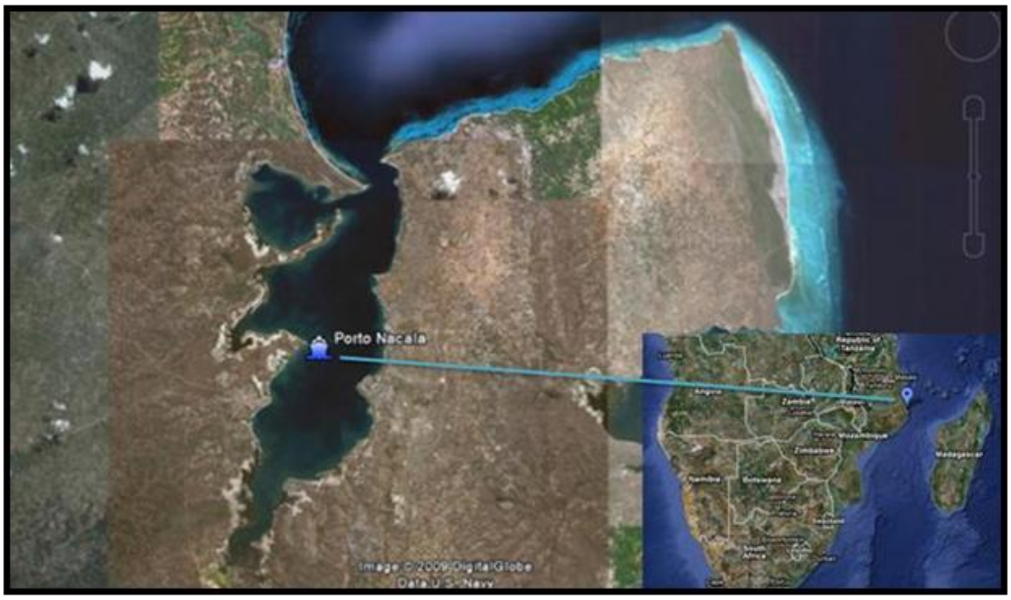

Figure 1 – Location of the Port of Nakala, in Mozambique.

The project is scheduled in 3 phases: 15, 25 and 40 Mtpa. Moreover, the company aims to gradually ramp up the production, which demands flexible layouts regarding capacity and expansion.

OBJECTIVES

This work aims to perform a technical assessment of the terminal, providing critical information about the performance of several layouts, such as demurrage costs, occupancy rate of the stockyard equipment, berths and car dumpers, as well as the average number of ships in queue and average waiting time.

METHODOLOGY

Regarding the simulation model development, the methodology was based on guidelines suggested by Pedgen et al. (1995) and modified by Botter (2002), as follows:

1. Definition of the problem;
2. Project planning;
3. System definition;
4. Conceptual model formulation;
5. Preliminary experimental design;
6. Input data preparation;
7. Model formulation;

8. Model verification and validation;

9. Final experimental design;

10. Testing and sensitivity analysis;

11. Analysis and interpretation;

12. Implementation and documentation.

At the same time, the studies of Chwif and Medina (2006) guided the development of the simulation tool, structuring it in 3 main stages:

- Design: the system and the goals are defined, the data is gathered and conceptual model is made;

- Implementation and Analysis: the computational model is produced, verified and validated;

- Analysis: simulations and analysis of results are carried out. If the results are not satisfactory, a new cycle should be started.

The methodology is presented as following in the Figure 1.

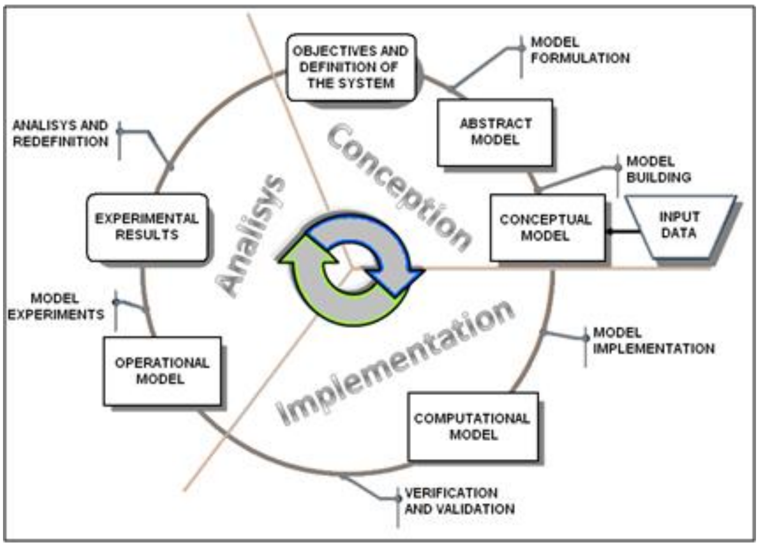

Figure 2: Methodology of a simulation model development. (Chwif (1999))

What concerns mining systems, Basu and Baafi (1999) published about discrete event simulation of a mining system in Australia, evaluating various operational scenarios.
Rodolfo *et al* (2009) brought out a coal export system considering transshipment, where several layouts were simulated varying several parameters, such as loading rates and canal depth (due to tidal influence).

LAYOUTS

Once the simulation model and its interface were created, 15 layouts were designed, varying the following parameters:

- Nominal rate of the stockyard equipment, ship loaders and tippler;
- Quantity of equipment;
- Number of berths;
- Stockyard capacity.

Figure 3 shows all considered layouts.

PHASE	LAYOUT	STOCKYARD EQUIPMENT				SHIPLOADER		TIPPLER		STOCKYARD	
		STACKER	RECLAIMER	STACKER-RECLAIMER	NOMINAL RATE	QTTY	NOMINAL RATE	QTTY	NOMINAL RATE	STOCK PILES	TOTAL CAPACITY
PHASE 1 15 MTA	1A	2	1	-	4,500	1	9,000	1	5,100	2	900,000
	1B	-	-	2	4,500	1	9,000	1	5,100	2	900,000
	1C	3	2	-	5,100	1	5,100	1	5,100	4	900,000
	1D	-	-	2	5,100	1	5,100	1	5,100	4	900,000
	1E	-	-	2	5,100	1	9,000	1	5,100	4	900,000
PHASE 2 25 MTA	2A	3	2	-	4,500	1	9,000	1	6,450	4	1,800,000
	2B	-	-	4	4,500	1	9,000	1	6,450	4	1,800,000
	2C	4	3	-	5,100	2	5,100	1	6,450	6	1,600,000
	2D	-	-	3	5,100	2	5,100	1	6,450	6	1,600,000
	2E	-	-	3	5,100	1	9,000	1	6,450	4	1,600,000
PHASE 3 40 MTA	3A	4	3	-	4,500	1	9,000	2	6,450	6	2,700,000
	3B	-	-	6	4,500	1	9,000	2	6,450	6	2,700,000
	3C	5	4	-	5,100	2	5,100	2	6,450	8	2,500,000
	3D	-	-	4	5,100	2	5,100	2	6,450	8	2,500,000
	3E	-	-	4	5,100	1	9,000	2	6,450	5	2,500,000

*Equipment efficiency: 52%

Figure 3 – Layouts characteristics.

There are two different types of shiploaders: the one that operates at 9,000 tph is also able to receive coal from up to two reclaimers, while the 5,100 tph shiploader may only operate with one reclaimer.
Moreover, several parameters remained fixed in theses analyses, such as time to berth/unberth, time to position tippler (car dumper), fleet profile, train capacity, and so on. However, they will not be discussed in this study.

RESULTS

Phase 1 – 15 Mtpa

Five layouts were designed and simulated for 15 MTPA demand, and the main results are shown in Figure 4.

	1A	1B	1C	1D	1E
Cargo supplied / Demand (%)	100%	100%	100%	100%	100%
Average queuing time (days)	3,9	1,5	2,3	2,2	1,2
Average number in queue	2,2	0,8	1,3	1,2	0,7
Berth occupancy	81%	61%	73%	73%	57%
Shiploader average loading rate (tph)	2.304	3.265	2.611	2.611	3.570
Occupancy of StackerReclaimer 1 - Stacking	-	25%	-	26%	25%
Occupancy of StackerReclaimer 2 - Stacking	-	26%	-	26%	26%
Occupancy of StackerReclaimer 1 - Reclaiming	-	34%	-	31%	30%
Occupancy of StackerReclaimer 2 - Reclaiming	-	35%	-	30%	31%
Occupancy of Stacker 1	26%	-	13%	-	-
Occupancy of Stacker 2	26%	-	26%	-	-
Occupancy of Stacker 3		-	13%	-	-
		-		-	-
Occupancy of Reclaimer 1	69%	-	31%	-	-
Occupancy of Reclaimer 2		-	30%	-	-
Car dumper occupancy	48%	48%	48%	48%	48%
Demurrage per ton ($/t)	0,75	0,13	0,35	0,38	0,07

Figure 4 – Results for 15 Mtpa

Regarding demurrage costs, the best performance layout is 1E, followed by 1B. Both of them have a single shiploader operating at a nominal rate of 9,000 tph (thus able to receive cargo from up to two reclaimers).

Even though layout 1A has a 9,000 tph shiploader, the average loading rate was 2,300 tph, since there is just one reclaimer feeding its high capacity shiploader. Then, this layout was designed considering the second phase.

Besides, stockyard equipment were underused, as their occupancy were not greater than 35%.

The ramp up was also carried out, and the results are shown as follows (Figure 5).

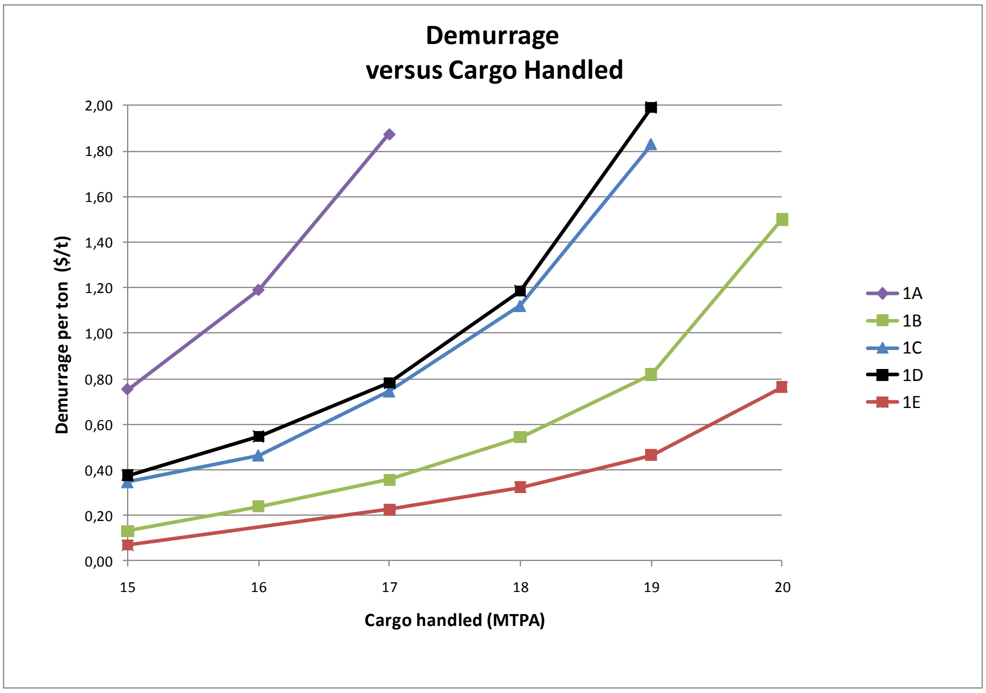

Figure 5 - Ramp up - Phase 1

The production ramp up was performed till 20 Mtpa. However, demurrage costs above $ 0.80 per ton were assumed to be impracticable. Thus, it is possible to assess the capacity of each layout, as follows (Figure 6).

Terminal Capacity - Phase 1

1A	1B	1C	1D	1E
15 MTPA	19 MTPA	17 MTPA	17 MTPA	20 MTPA

Figure 6 - Terminal capacity for each layout - Phase 1

The assessment above indicates when an expansion of the terminal would be necessary, for each layout, for higher demands.

Phase 2 – 25 Mtpa

For Phase 2, all layouts from the previous step were enhanced, maintaining their main characteristics, as shown previously in Figure 3. The results are shown in Figure 7.

	2A	**2B**	**2C**	**2D**	**2E**
Cargo handled / Demand (%)	100%	100%	100%	100%	100%
Average queuing time (days)	3,4	3,5	0,7	0,8	2,0
Average number in queue	3,7	3,7	0,8	0,9	2,1
Average Berth occupancy	88%	87%	68%	69%	80%
Berth 1 occupancy	88%	87%	74%	75%	80%
Berth 2 occupancy	-	-	63%	64%	-
Shiploader 1 average loading rate (tph)	4.574	4.584	2.608	2.572	5.150
Shiploader 2 average loading rate (tph)	-	-	2.606	2.566	-
Occupancy of StackerReclaimer 1 - Stacking	-	21%	-	25%	26%
Occupancy of StackerReclaimer 2 - Stacking	-	20%	-	25%	25%
Occupancy of StackerReclaimer 3 - Stacking		19%		26%	26%
Occupancy of StackerReclaimer 4 - Stacking		16%		-	-
Occupancy of StackerReclaimer 1 - Reclaiming	-	35%	-	38%	37%
Occupancy of StackerReclaimer 2 - Reclaiming	-	33%	-	38%	39%
Occupancy of StackerReclaimer 3 - Reclaiming		33%		38%	38%
Occupancy of StackerReclaimer 4 - Reclaiming		29%		-	-
Occupancy of Stacker 1	22%	-	13%	-	-
Occupancy of Stacker 2	38%	-	25%	-	-
Occupancy of Stacker 3	16%	-	25%	-	-
Occupancy of Stacker 4	0%	-	12%	-	-
		-		-	-
Occupancy of Reclaimer 1	65%	-	38%	-	-
Occupancy of Reclaimer 2	65%	-	38%	-	-
Occupancy of Reclaimer 3	-	-	38%	-	-
Car dumper occupancy	70%	70%	70%	70%	70%
Demurrage per ton ($/t)	0,49	0,50	0,01	0,03	0,16

Figure 7 - Results for 25 Mtpa

Regarding demurrage costs, the best performance layout was 2C, followed by 2D. However, both layouts operate with two berths, unlike the others.
Moreover, except for 2C and 2D, berth occupancy was elevated in all layouts.
The ramp up is show in Figure 8.

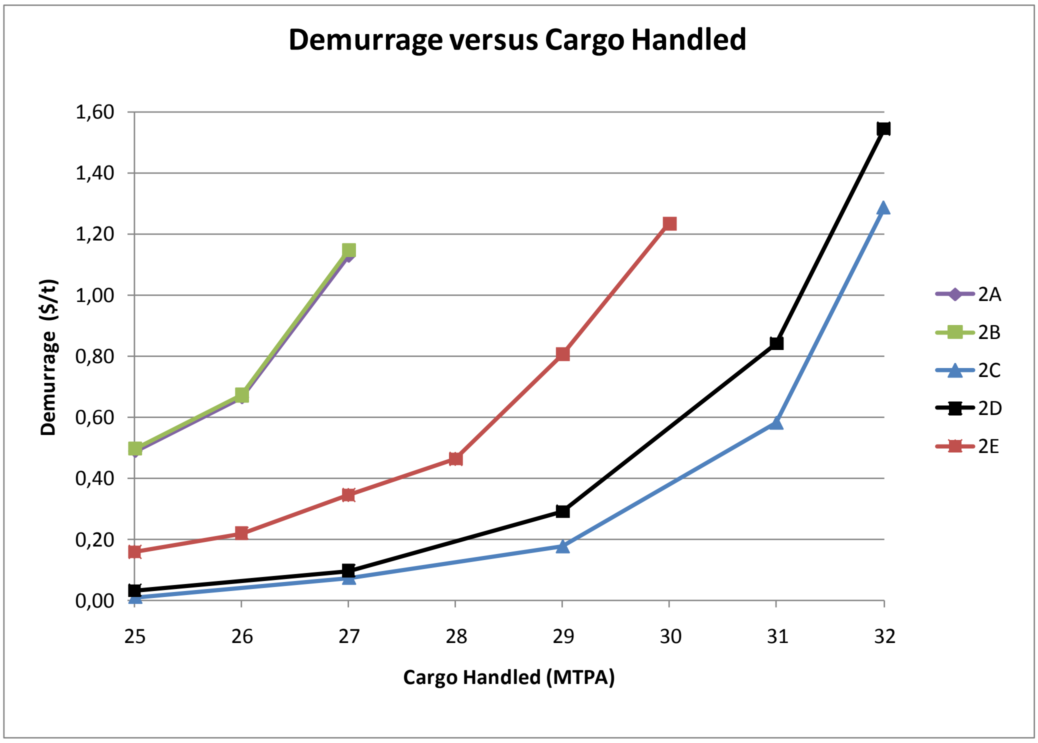

Figure 8 – Ramp up – Phase 2

Assuming that demurrage costs above $ 0.80 are impracticable, the terminal capacity was determined as shown in Figure 9.

Terminal Capacity - Phase 2

2A	2B	2C	2D	2E
26.2 MTPA	26.2 MTPA	31.2 MTPA	30.8 MTPA	29 MTPA

Figure 9 - Terminal capacity for each layout - Phase 2

Phase 3 – 40 Mtpa

For Phase 3, all layouts of the previous step were enhanced, maintaining their main characteristics. The results are shown in Figure 10.

	3A	3B	3C	3D	3E
Cargo handled / Demand (%)	100%	100%	100%	100%	100%
Average queuing time (days)	0,9	0,4	0,4	0,9	1,7
Average number in queue	1,4	0,6	0,7	1,3	2,7
Average Berth occupancy	85%	76%	79%	84%	92%
Berth 1 occupancy	89%	82%	88%	92%	93%
Berth 2 occupancy	81%	70%	80%	84%	91%
Berth 3 occupancy	-	-	68%	75%	-
Shiploader 1 average loading rate (tph)	3.947	4.577	2.611	2.405	4.600
Shiploader 2 average loading rate (tph)	3.734	4.574	2.611	2.414	2.413
Shiploader 3 average loading rate (tph)	-	-	2.611	2.396	-
Occupancy of StackerReclaimer 1 - Stacking	-	19%	-	28%	30%
Occupancy of StackerReclaimer 2 - Stacking	-	19%	-	29%	26%
Occupancy of StackerReclaimer 3 - Stacking	-	19%	-	29%	30%
Occupancy of StackerReclaimer 4 - Stacking	-	19%	-	-	30%
Occupancy of StackerReclaimer 5 - Stacking	-	19%	-	-	-
Occupancy of StackerReclaimer 6 - Stacking	-	19%	-	-	-
Occupancy of StackerReclaimer 1 - Reclaiming	-	32%	-	43%	42%
Occupancy of StackerReclaimer 2 - Reclaiming	-	33%	-	43%	43%
Occupancy of StackerReclaimer 3 - Reclaiming	-	33%	-	43%	43%
Occupancy of StackerReclaimer 4 - Reclaiming	-	33%	-	44%	44%
Occupancy of StackerReclaimer 5 - Reclaiming	-	33%	-	-	-
Occupancy of StackerReclaimer 6 - Reclaiming	-	33%	-	-	-
Occupancy of Stacker 1	20%	-	14%	-	-
Occupancy of Stacker 2	39%	-	28%	-	-
Occupancy of Stacker 3	39%	-	28%	-	-
Occupancy of Stacker 4	16%	-	28%	-	-
Occupancy of Stacker 5	-	-	14%	-	-
Occupancy of Reclaimer 1	66%	-	43%	-	-
Occupancy of Reclaimer 2	66%	-	44%	-	-
Occupancy of Reclaimer 3	65%	-	43%	-	-
Occupancy of Reclaimer 4	-	-	43%	-	-
Commitment Virador	65%	65%	65%	65%	65%
Demurrage per ton ($/t)	-0,02	-0,12	-0,04	0,06	0,16

Figure 10 - Results for 40 Mtpa

Although layouts 3C and 3D operate with three berths, the best performance layout regarding demurrage costs was 3B, followed by 3A. This apparently contradiction is due to the shiploader capacity, which provides a higher average loading rate, and consequently best performance.

Besides, the demurrage costs in Layout 3E are acceptable in comparison with the maximum demurrage assumed ($ 0.80 per ton). Moreover, there are only two berths, one 9,000 tph shiploader and one 5,100 tph shiploader, which suggest that this layout is probably less costly than the others considered.

CONCLUSIONS

Five layouts were designed and simulated for each phase, providing valuable information for several analyses, as well as for capacity evaluation, which was based on demurrage costs per ton.

A range of possible solutions is seen in this study, and the decision on the best performance layout relies on demurrage costs, capital and operational expenditure (CAPEX/OPEX), ramp up speed and maximum expected demand. Moreover, the decision maker must consider not only the operational and financial performance, but the ramp up schedule, in order to not underuse the terminal during the ramp up.

Finally, the use of simulation methodology succeeded in providing critical information about several layouts, for different demands.

BIBLIOGRAPHY

PEDGEN, C.D.; SHANNON, R.E. and SADOWSKI, R.P. (1995). Introduction to simulation using SIMAN, McGraw-Hill. 2ª Edição. New York.

BOTTER, R.C. (2001). Introdução às técnicas de simulação e ao programa Arena. Apostila do curso oferecido no departamento de Engenharia Naval e Oceânica da Universidade de São Paulo.

BOTTER, R.C. Tratamento de dados em simulação discreta, Tese (Livre-Docência) – POLI - USP, Dpto. de Eng. Naval e Oceânica, São Paulo, 2002.

CHWIF, L. and MEDINA, A.C. (2007). Modelagem e Simulação de Eventos Discretos: Teoria & Aplicações, 2 ª Edição.São Paulo, 254 p.

CHWIF, L (1999). Redução de modelos de simulação de eventos discretos na sua concepção: uma abordagem causal. Tese de Doutorado. Escola Politécnica da USP. Departamento de Engenharia Mecânica.

BASU, A. J. and BAAFI, E. Y. (1999). Discrete event simulation of mining systems: current practice in Australia. International Journal of Surface Mining, Nalkeema, v. 13, p. 79 – 84.

SILVA, R. C. S., BOTTER, R. C., TREVISAN, E. F. C., MEDINA, A. C., PEREIRA, N. N. and NETTO, J. F. (2009). Planejamento de um sistema de transshipment para a exportação de carvão utilizando simulação de eventos discretos. XXI COPINAVAL, Montevideo, Uruguay.