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RELIABILITY OF LARGE SCALE CONVEYOR SYSTEMS
A Simulation Approach

Jaap A. Ottjes and Gabriel Lodewijks
Delft University of Technology, Faculty of
Mechanical Engineering and Marine Technology
Mekelweg 2, 2628 CD Delft, The Netherlands
J.A.Ottjes@wbmt.tudelft.nl

KEYWORDS

Transport, conveyor system, reliability, process oriented simulation

ABSTRACT

The overall performance of industrial conveyor systems for bulk depends on the reliability of individual system components and their arrangement. A model for dimensioning of large scale systems in the early design stage is discussed. In the model discrete event simulation is used for the modelling of equipment reliability and simple numerical integration is applied for the stacking and loading processes. With the model stock pile dimensions, production flow and service rates of a mineral export terminal can be determined. The use of the model is illustrated with a case. The model is generic with respect to equipment break down distributions and customer characteristics. In case of different equipment arrangements the model logic has to be adapted.

INTRODUCTION

Conveyor systems in the mining industry consist of serial and parallel connections of equipment. Equipment may be mining equipment, belt conveyors, train load-out stations, stacking and reclaiming equipment and (ship) loading equipment. Some stages in the transportation chain are uncoupled by a stockpile or redundantly implemented. Besides redundancy, another reason for decoupling conveyor system often is the difference in system dynamics (Lodewijks, 2001). The overall reliability is composed of the individual reliabilities of all equipment. Reliability is defined as the average percentage of time the material flow is guaranteed. System reliability determines the service rate that can be offered to customers. Customers in this case are buyers of the minerals quarried in the mine. They collect the product by train or ship. In some cases the customer is a power plant that is directly connected to the mine.

In this paper we focus on sea transportation and define customer service in terms of waiting time of ships that collect the product. Apart from the characteristics of the loading system, the arrival pattern of ships plays an important role as well. Statistical analysis of such a system is intractable. Simulation offers a flexible way of analysing complex systems. A model will be presented and a case will be worked out to illustrate the use of the model. The model has been used in practice already for design and tender purposes. The case itself and the data used are fictitious. In the case the focus is on the determination of the stockpile size and on the effect of the system's reliability on ship waiting times.

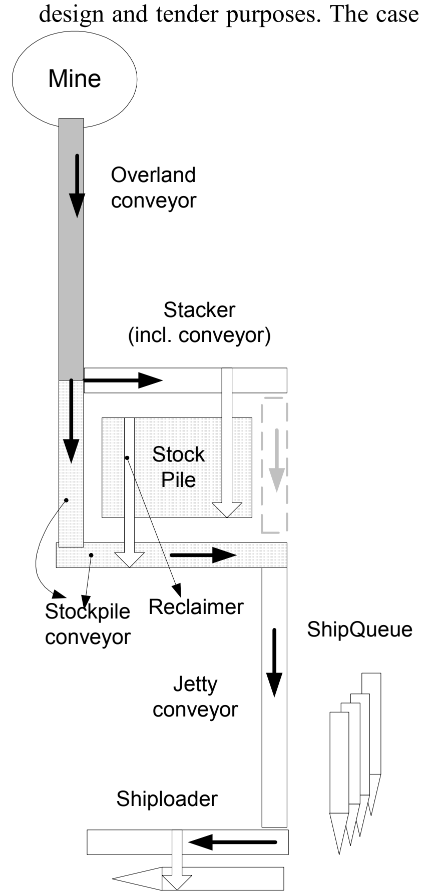

Figure 1. Schematic drawing of the terminal system. The overland- and jetty conveyor usually are several kilometres in length. The dotted conveyor in the figure denotes a redundancy or extra by-pass conveyor. It is not modelled.

CASE DESCRIPTION

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An inland coal mine is connected to a ship loading facility by means of a conveyor system. Figure 1 shows a schematic drawing of the terminal system. The material flow can be directed either to a stockpile via a stacker system or can be bypassed for direct loading into a ship. Stacking is done if there is no ship available or if the downstream line is blocked
by disturbances of the downstream equipment. A

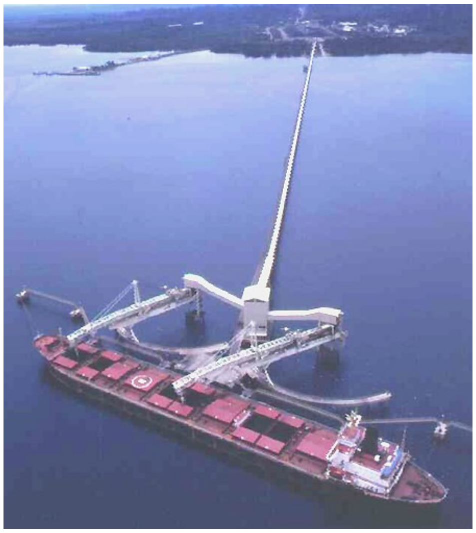

Figure 2. Example of a Jetty Conveyor Feeding the Ship Loading Equipment. The length of the conveyor is 2 km. and the transport capacity is 4200 MTPH. (Kaltim Prima Coal Mine).

Figure 3: Ingwe Overland Conveyor System in South Africa

reclaimer may add its reclaim flow to the load flow as long as there is a ship to be loaded, as long as the stockpile is not empty, and as long as the combined flow does not exceed the capacity of the ship loader. The load flow is further directed via a jetty conveyor to a ship loader. Figures 2 and 3 show examples of installed equipment.

MODELING

For the modelling the process-interaction approach is used (Zeigler 2000; Fishmann 2001). In this approach the system is virtually broken down into relevant element classes each with their typical attributes. By doing so an object oriented data structure of the system is obtained. Next, for all active element classes the process descriptions are to be defined. A process describes the functioning of an active element as a function of time. In this way the dynamic functioning of each element of the class is obtained. The last step is to create all necessary elements according to their classes and to start the element-processes. In the simulation model all active elements act parallel in time, synchronized by the sequencing mechanism of the simulation software.

The modelling of the equipment work-down cycle, the ship process, the stock pile and the actual conveying processes will be explained successively in pseudo code (Ottjes and Veeke 2003). Pseudo code has the advantage that it is communicable with (conveyor system) experts and can easily be implemented in formal computer code provided a proper simulation tool is used. (Healy and Kilgore, 1997; Veeke and Ottjes, 2000) A crucial conception in process interaction modelling is the ‘Advance’ clause. If it is encountered in a process then the element is halted for a certain time. During that time other elements may proceed. Consequently the processes are running in parallel.

Equipment Work-Down Cycle

The equipment work-down cycle time t_c is defined as

$$t_c = t_w + t_d \qquad (days)$$

in which t_w depicts the average undisturbed working time and t_d the average down time in one cycle. It is assumed that down time occurrences of the equipment are independent within the system boundaries.

Table 1. Element Class Equipment: attributes and process

attributes:

- Name
- WorkTime _distribution // with average t_w
- DownTime _distribution // with average t_d
- Availability // a = 100 t_w / t_c (%)
- Standard_Flow (ton/hour)
- Actual Flow (ton/hour)
- Working (1: operational or 0:not operational)

Process

```
Repeat
   ActualFlow = StandardFlow
   Working = 1
   Advance (Sample(WorkTimeDistribution))
   ActualFlow = 0
   Working = 0
   Advance(Sample(DownTimDistribution))
```

That implies that for the modelling one element class suffices for all equipment. The element class is called "equipment". It owns attributes and a process description as shown in table 1. The distributions used are model-input and may be of any analytical or tabulated form. Varying the distribution type or its parameters allows investigation of the influence of this variation on the outcome of the simulation.

Table 2 shows a fictitious model input with definitions of the distributions of working periods of each system component. For the stacker for example, it means that the undisturbed working periods are normally distributed with an average of 20 days and a standard deviation of 5 days. After a working period a down period follows. The average length of this period (t_d) depends on the availability and the average undisturbed working period. The relationship is given in the next equation.

$$t_d = t_w(\frac{100}{a} - 1) \qquad (days)$$

With a representing the availability. Each distribution realized during a simulation run is reproducible.

Table 2. typical model input for capacity and availability of system components

Eq. Name	Std. Flow T/h	Availa-bility %	Work Time Distribution (days)
Overland Conv	1200	97	Exponential(14)
StockPile Conv.	1200	97	Exponential(21)
Jetty Conv.	3600	97	Exponential(21)
Loader	3600	97	Uniform(1,5)
Stacker	1200	90	Normal(20,5)
Reclaimer	2400	85	Table(2,0,6,70,45,100)

Ship Modelling

A mining production facility usually has customers that collect approximately fixed loads of product by ship on a regular basis. Their ships arrive at regular times and the demand is a constant. Customers may originate from all over the world.

Ships are supposed to be characteristic for their origin. In the model for each origin a characteristic ship is created that moves the total year demand to its origin. It has a fixed load demand and a cycle time that corresponds with the yearly total demand. The cycle time may have a random component. The ship class is defined in table 3. Statistics of the ShipQueue and the JettyQueue are monitored during simulation.

In table 4 the input file used in the model is shown.

Table 3. Element Class ship: Attributes and Process

```
attributes:
 -DWT
-TonsLoaded
-Year Demand
-CycleTime distribution     // average and deviation
-Tug handling data
-Preparation data
-Hatch handling data

Process
Repeat
   Advance Sample(Cycle time Distribution)
   Enter ShipQueue
   Advance until (ShipQueue.First AND JettyQueue=Empty)
   //wait for room at the jetty
   Advance TugToJettyTime
   Leave ShipWaitingQueue
   Enter JettyQueue
   Advance TimePrior+HatchTime
   LoadShip = SELF
   Advance  //ship is now being loaded
   Advance (TimeAfter)
   Advance TugFromJettyTime
   Leave JettyQueue
```

```
Table 4. Typical Ship Input
_________________________________________
(1) Destination
(2) DWT (Tons)
(3) Year demand (kTons)
(4) Std.Deviation ship cycles time (%)
(5) Tug to Jetty time (h)
(6) Time prior (h)
(7) Hatch Time (h)
(8) Time after (h)
(9) Tug from Jetty Time (h)
__________________________________________
   (1)      (2) (3)  (4)  (5)  (6)  (7)  (8)(9)
'Europe'   155 1950 20 165 355 549 520 50
'Germany'  110  650 20 145 310 311 440 40
'Taiwan'   110  650 20 145 310 311 440 40
'Italy'     70  650 20 115 370 249 480 30
'Hong Kong' 70  390 20 115 370 249 480 30
'Indonesia' 70  390 15 115 370 249 480 30
'Korea'     55  390 15 110 275 208 370 30
'Hawaii'    55  650 20 110 275 208 370 30
'Malaysia'  55  195 20 110 275 208 370 30
'Japan'     40 1170 15 100 325 176 395 30
'USA'       30 1300 20  55 240 136 245 30
'Australia' 40  715 20 155 365 126 515 50
```

The Stockpile

The stockpile class is defined in table 5. Its process is monitoring its contents at regular times and registering it for further statistical analysis.

Table 5. Element Class Stock pile: Attributes and Process
Attributes
- MaxContent
- MinContent
- Content
- NotEmpty (=0 if empty and =1 if not empty)
- Monitor_timestep // 1 hour is used
Process
Repeat
Advance monitor_timestep
Register Content

The Actual Conveying Processes

Until now only the equipment work-down cycle is modelled. From that we know for each machine its status in terms of possible and actual material flow. In order to get an accurate representation of the conveyed material flow and the ship loading operation, three system components are relevant: The Stacker, filling the stockpile, the Reclaimer taking the material from the stockpile and the Shiploader that loads de ships one by one. The production (tons) of each can be determined by integrating the relevant material flows. In the simulation model the material transportation time is ignored, which means that the conveyor system's dynamics in terms of mass are ignored, (Lodewijks 2002). As a consequence of ignoring material transportation time, material produced by the Reclaimer is loaded by the ShipLoader into the ship instantly. Therefore the Shiploader and Reclaimer can be combined. We solve the stacking and loading process by simple numeric integration incorporated in the processes of stacker and Loader/Reclaimer.

Table 6. Element Class Stacker: Attributes and Process
attributes
-StackBatch
-TimeStep // 0.5 hours is used
Process
Repeat
-Advance TimeStep
-StackBatch = TimeStep*Stacker.Working * OverlandConveyor.ActualFlow
-if Loader.LoadBatch =0 AND StockPile.Contents < StockPile.MaxContents then StockPile.Contents = StockPile.Contents + StackBatch
-If StockPile.Contents> MinContents then StockPile.NotEmpty= 1

Mind that both the ShipLoader and the Reclaimer have their own break down processes. The Stacker element class is shown in table 6. The Reclaimer/ShipLoader element class will further be referred to as "Loader". It is described in table 7. In the loader both reclaiming and ship loading processes are incorporated. The loadBatch may either be formed by the direct flow from the mine or by the reclaimed flow from the StockPile or by the sum of both.

Table 7. Element Class Loader: Attributes and Process
Attributes
-StockBatch
-LoadBatch
-DownStreamWorking (0 or1)
-Timestep // 2 hours is used
Process
Repeat
Advance TimeStep
If LoadShip <> Nil then
- DownStreamWorking= StockPileConveyor.Working * JettyConveyor.Working * Loader.Working
- StockBatch = TimeStep * Reclaimer.ActualFlow * StockPile.NotEmpty * DownStreamWorking
-StockPile.Contents = StockPile.Contents – StockBatch
-LoadBatch=StockBatch + TimeStep * OverlandConveyor.ActualFlow * DownStreamWorking
-LoadShip.TonsLoaded = LoadShip.TonsLoaded + LoadBatch
- If StockPile.Contents < StockPile.MinContents then StockPile.NotEmpty = 0
- If LoadShip.TonsLoaded > LoadShip.DWT then
-LoadShip.Resume
-LoadShip = Nil
Else LoadBatch = 0

DESIGNING

In this section the global design process using the model will be discussed. The role of equipment reliability is essential in this example. We suppose that the availability is only approximately known because the system is intended to function in a hostile climatological environment with a lack of skilled maintenance personnel. In a real case the design process would start with an expert estimate of the availability and operation of each piece of equipment.

We use the availability data of table 2 and for all equipment a negative exponential distribution with average 21 days for the working time period. The down time is taken to be uniformly distributed between 0.5 t_d and 1.5 t_d. Further we use table 4 for the ships input data. This configuration is called "reference case". Planned overhaul is not included in the analyses. Improving maintenance however may be a means to improve system performance.

Prior to the system analysis the standard run length is determined. To that end a number of runs have been performed with the reference input but different random streams for the distributions used. It appears that with a run length of 10 years the standard deviation with respect to the average ship waiting times amounts to 5%. The standard run length is set to 10 years.

Entries 1576 90% Quantile 100.3
Mean 36.5 Std.Deviation 45.1

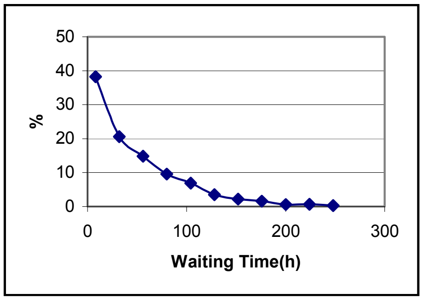

Figure 4a:Distribution of Ship Waiting Times. Reference Run with Stock Pile Capacity of 350 kTon

Entries 8759 90% Quantile 283.3
Mean 177.7 Std.Deviation 82.2

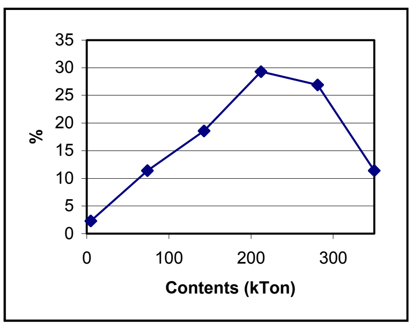

Figure 4b: Distribution of Stock Pile Contents. Reference Run with Stock Pile Capacity of 350 kTon

The individual runs with the model provide distributions of ship waiting times and stock pile contents. Figures 4a and 4b show examples of that. These statistical data are used to further carry out the analysis. First the order of magnitude of the required stockpile capacity is to be determined. This is done by measuring the ship-waiting times under variation of the stockpile capacity. The results are shown in figure 5. Both the average ship-waiting times are plotted and the 90% percentiles of the waiting times.

A certain point on the 90% percentile curve means that 90% of the waiting times were lower than the corresponding waiting time value. From this graph it was concluded that a ´safe´ stockpile capacity would be 700,000 Ton. Next the sensitivity of that choice for variations in the equipment availability is evaluated. By varying the equipment availability around the reference values in table 2 in steps of 1%, figure 6 is obtained. It shows the percentage of time the stockpile has been empty and consequently could not function well. It appears that the reference availability values have some margin of 1 % left.

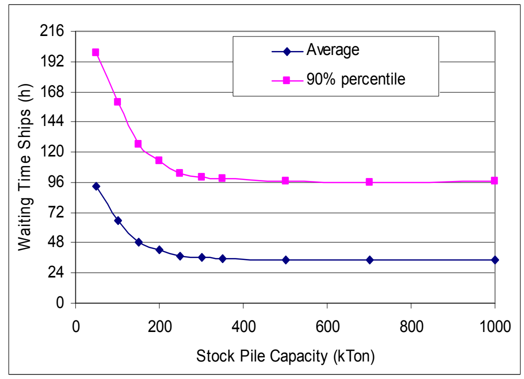

Figure 5: Ship-Waiting Times as a Function of the Stockpile Capacity

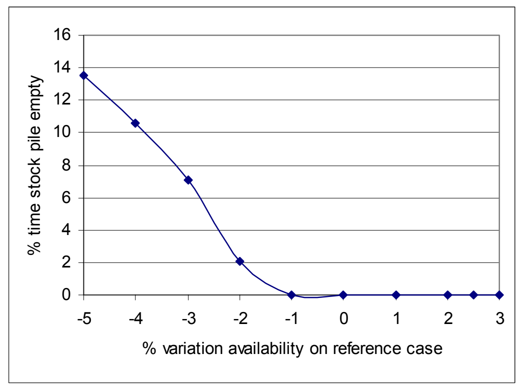

Figure 6: Percentage of Time the Stockpile was Empty as a Function of Varying Equipment Availability

Finally the influence of availability variations on the ships waiting times is determined. The results are given in figure 7 showing that the average ship waiting time for the reference case will be about 36 hours. A demand on the customer service may be that the average waiting time of ship before loading should not exceed 36 hours. If this demand for example would be 24 hours, a way to reduce the waiting times down to 24 hours is to improve the availability by improving maintenance, or to increase the capacity of the system components. Several other ways to find methods for tuning the system and improving the overall performance are possible but not further discussed in this paper. Some are:

- Investigating the influence of each piece of equipment separately.
- Determination of the influence of ship-arrival time deviations. One way of improvement could be the coordination of the ships-arrivals.
- Varying the shape and parameters of the down-time distributions and down time distributions that are based on measurements and experience

from practice.

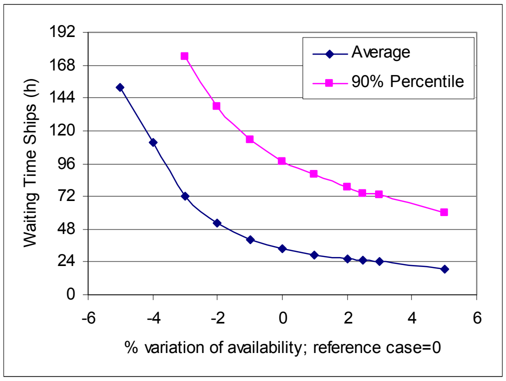

Figure 7: Ship-Waiting Times as a Function of Varying Equipment Availability

CONCLUSIONS

A model is presented to determine production flow and service rate of mineral export terminals taking into account the reliability of the individual system components. The use of the model is illustrated with a case. First the stock pile dimension is determined and after that the sensitivity of the ship-waiting times. for the reliability of the equipment is investigated. The model is generic with respect to equipment break down distributions and number, arrival patterns and demand of customers. For terminals with a different equipment composition the model-logic has to be adapted.

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