# IMPROVING LOGISTICS IN THE ASPHALT PAVING PROCESS - WHAT CAN WE LEARN FROM THE PLANNER'S LOGIC? [1]

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Significant public procurement changes are forcing road construction companies to professionalise planning and control of asphalt paving projects. In an effort to outperform competitors, companies seek better control over the paving process, over the planning and scheduling of resources and work, and over performance. For the asphalt paving companies to be able to improve product and process performance, they now - more than ever - acknowledge they need to develop intricate understanding of the asphalt paving process and the interdependencies with the logistics. We focus on lessons learnt from an analysis of truck resources used in the asphalt paving process on three road construction projects in the east of The Netherlands. The aim is to explore the decision-making process and unravel the logic that planners use in determining truck resources for transporting asphalt from the asphalt plant to the construction site. Three methods are used to firstly, analyse and secondly, compare resource allocation. The methods are calculations based on fleet-demand principles, calculations based on the National Highway Institute Method and an analysis using the EZStrobe simulation software. The results show that all three methods provide the planner with more accurate means of determining the truck resources required for the transport of asphalt from the plant to the site. It appears that the planner has not considered the differing travel distances and cycle times in determining truck resource requirements. This work is ongoing and forms part of an overall action research study aimed at improving the logistics operations within the asphalt paving process through exploring the choices planners make in determining and allocating essential resources.

Keywords: modelling, simulation, productivity, logistics, asphalt.

## INTRODUCTION

The Dutch construction industry is changing. The collusion structure that regulated competition has fallen apart (Dorée et al. 2003, Dorée 2004). Public clients have introduced new contracting schemes containing incentives for better quality of work (Sijpersma et al. 2005). New types of contracts, tougher competition and the urge to make a distinction in the market, spur companies to advance in product and process improvement. These changes have significantly altered the playing field for competition. The companies see themselves confronted with different “rules of the game” than what they were used to. Performance contracting and longer guarantee periods create a new set of risks and business incentives (Ang et al. 2005). In general, the companies

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experience the pressure of new types of competition and other rules and trends, but at the same time, they acknowledge the opportunity to distinguish themselves. Road construction companies, in turn, seek better control over the construction process, over the planning and scheduling of resources and work, and over performance. Improved control would also reduce the risks of failure during the guarantee period. To be able to achieve these goals, the relevant on-site operational parameters need to be known and the relationships between these parameters need to be thoroughly understood. For asphalt paving companies to be able to improve product and process performance, they now more than ever acknowledge they need to develop intricate understanding of the asphalt paving process and the interdependencies within the process.

## SCOPE AND OBJECTIVE OF STUDY

Uniformity of operations is essential in asphalt hot-mix paving. Uniform, continuous operations of the paver produces the highest quality pavement (Asphalt-Institute 1989, NCAT 1996). There is no advantage in the paver travelling at a speed that requires the mix to be supplied faster than the asphalt plant can produce it. Trying to pave too quickly can result in the paver having to stop frequently to wait for trucks to bring more mix. If the wait is too long (more than a few minutes on a cool day) the smoothness of the pavement will suffer when the paver starts up again as the mix in the paver that has cooled off is used up. The effect of temperature differentials on the asphalt paving process has been documented extensively (Read 1997, Stroup-Gardiner 2000, Stroup-Gardiner et al. 2002, Willoughby et al. 2002). Obviously, then it is essential that plant production and paving operations be coordinated. The paver must be continuously supplied with enough mix, and at the same time, the trucks should not have to wait a long time to discharge their loads into the paver hopper (Asphalt-Institute 1983). Also, in the asphalt paving process, the essential criterion from a contractor's perspective is the productivity of the asphalt paving operation. The number of trucks used in the asphalt paving cycle is therefore critical to ensure that the paver is supplied with enough asphalt mix. A smoother operation and a higher quality of pavement may prevent potential problems relating to stop-and-go operations such as unnecessary construction joints, inconsistent material density and low pavement smoothness (Asphalt-Institute 1983, Asphalt-Institute 1989, NCAT 1991, Freitas et al. 2005). A few questions then arise. How many trucks should be used to achieve the target productivity? What is the effect of deviations in truck numbers on productivity? The aim of this paper is to explore the decision-making process and unravel the logic that planners use in determining truck resources for transporting asphalt from the asphalt plant to the construction site. This forms part of an overall action research study aimed at improving the logistics operations within the asphalt paving process through exploring the choices planners make in determining and allocating essential resources.

## PLANNER'S LOGIC

The projects selected for this study were the resurfacing of a freeway, a provincial road and an urban collector street, all in the east of The Netherlands. The project details are given in Table 1. Operational data was collected at the three project sites over a 16-day period (waiting, loading, travel times, etc.). Two plants supplied asphalt for the freeway and provincial roads, each resulting in different travel distances from the plant to the work zone. Closer inspection of the actual number of trucks allocated shows inconsistencies in the logic of the planners. The travel distances between plant and sites vary between the projects. The traffic conditions vary since the trucks are travelling on different classes of roads. In addition, the asphalt paving process is influenced by the rate of asphalt mix delivery from the asphalt plant to the work zone/construction site. The amount of asphalt to be delivered in a period is a function of the number of trucks, their capacities and the cycle times of the trucks. More importantly, the delivery productivity is determined solely by the cycle times of the trucks since the truck capacities are more or less fixed. However, when the cycle times change, the rate of material delivery changes and this mostly affects the production rates of paving and compaction operations in a negative way. Nevertheless, despite the differing travel distances and therefore cycle times, it appears that the planners have not considered them in determining resource requirements. The number of trucks for both the A35 freeway and the N18 provincial road has remained the same despite the distance from the asphalt plant to the road construction site and the average travel time almost doubling (see last column of Table 1). A few questions then arise. What logic are planners applying in allocating resources for the asphalt paving process? What choices do the planners have in making a more precise estimate of the trucks that should be allocated to the various sites? What methods could be used to be more consistent in the allocation of trucks?

*Table 1 - Project details*

| Road | Class of road | Asphalt laid (tons) | Area surfaced (m²) | Distance from plant to site (km) | | Average travel time (mins) | Actual no of trucks allocated |
|---|---|---|---|---|---|---|---|
| A35 | 4-lane Freeway | 6015 | 42450 | Deventer to A35 | 44 | 45 | 9 |
| | | | | Nijkerk to A35 | 106 | 90 | 9 |
| N18 | 2-lane Provincial | 1400 | 18530 | Deventer to N18 | 58 | 65 | 8 |
| | | | | Nijkerk to N18 | 120 | 110 | 8 |
| Emma street | Local street | 640 | 5370 | Deventer to Emmastreet | 62 | 57 | 5 |

## DETERMINING RESOURCE REQUIREMENTS

As mentioned earlier, the major factor that influences the whole asphalt paving process is the rate of asphalt mix delivery from the asphalt plant to the construction site. Thus, the contractor has to estimate the number of trucks to be used in the asphalt paving cycle. The calculations can be done in two ways viz. an algebraic method based on basic fleet-demand principles and asphalt mix delivery production estimates based on a spreadsheet method developed by the National Highway institute (NHI) in the USA. In both, rather similar methods, the calculations give the contractor a rough estimate of the minimum number of trucks that could be used for a project given the target production for the day, the number of working hours, and an approximation of waiting and loading times. However, both methods do not take into account the stochastic effect inherent in construction. This stochastic effect can be modelled using simulations. Simulation is widely regarded as an effective tool for process analysis based on its power for handling complex interactions (Halpin et al. 2003). Despite the advantages, construction practitioners make little use of simulation to handle complex production systems. Several authors argue that the construction industry typically lags behind other industries in adopting technology. They are rather critical of the construction industry and the slow progress in adopting technology to assist construction processes (AbouRizk et al. 1992, Halpin et al. 1999). Nevertheless, a great deal has been accomplished to encourage the use of simulation in the construction industry. Several simulation tools have been developed. CYCLONE (Halpin 1973), DISCO (Halpin and Huang 1995), STROBOSCOPE (Martinez et al. 1994) and EZStrobe (Martinez 1998) all significantly reduce the complexity involved in modelling construction processes. Practitioners are able to design graphical models, assess the state of simulation and check on the resource flow involved in construction operations. Compared with analytical methods, simulation has the advantage of addressing the dynamic and stochastic nature involved in construction operations. As a result, numerous successful applications of simulation in construction have been documented (Pilcher et al. 1984, David 2001, Bowden et al. 2006).

### Method 1 - Fleet-demand principles

The cycle time between asphalt plant and the construction site can be calculated as a function of the distance plant - site, and the average waiting and loading times.

$$Cycle\,time = 2 * L * \frac{60}{S} + \left[W_p + L_p + W_s + U_s\right] \qquad (1)$$

Where:

- L = distance between plant and site
- S = average speed between plant and site
- Wp = waiting time at the plant
- Lp = loading time at the plant
- Ws = waiting time at the site
- Us = unloading time at the site

The number of trucks needed can be calculated as a function of the vehicle capacity and the quantity of material to be transported per hour. Given the target production for the day and the number of working hours in the day, the minimum headway for truck arrivals on the site and the minimum number of trucks required can be calculated.

$$H_m = \frac{C * 60}{D} \qquad (2)$$

Where:

- Hm = Minimum headway between truck arrivals
- C = average truck capacity
- D = quantity of asphalt to be transported per hour

$$Number\ of\ trucks\ required = \left[\frac{2 * L * D}{S * C}\right] + \left[\frac{D * \left(W_p + L_p\right) * (W_s + U_s)}{C * 60}\right] \qquad (3)$$

Using fleet-demand principles, the estimated number of trucks required for the various sites are shown in Table 2.

*Table 2 - Trucks required based on fleet-demand calculations*

| | Deventer to A35 | Nijkerk to A35 | Deventer to N18 | Nijkerk to N18 | Deventer to Emma |
|---|---|---|---|---|---|
| Number trucks required | 7 | 11 | 5 | 7 | 4 |

## Method 2 - National Highway Institute (NHI) method

Asphalt mix delivery production can also be done using the NHI method (National-Highway-Institute 1999). The method is similar to the algebraic fleet-demand calculation and has the advantage of being set up in a simple spreadsheet for ease of calculation and interpretation. Using the NHI method, the estimated number of trucks required for the various sites are shown in the last row of Table 3.

*Table 3 - Trucks required based on NHI method calculations*

| | unit | Deventer to A35 | Nijkerk to A35 | Deventer to N18 | Nijkerk to N18 | Deventer to Emma |
|---|---|---|---|---|---|---|
| Asphalt mix to be placed | tons | 752 | 752 | 352 | 352 | 320 |
| Work hours | hrs | 8 | 8 | 8 | 8 | 8 |
| Rate of mix delivered to site | t/hr | 94 | 94 | 44 | 44 | 40 |
| Rate of mix from asphalt plant | t/hr | 94 | 94 | 44 | 44 | 40 |
| Average truck capacity | tons | 28.9 | 30.3 | 28.9 | 30.3 | 28.9 |
| Total truck trips needed | no | 26.1 | 24.8 | 12.2 | 11.6 | 11.1 |
| Load time | mins | 5 | 6 | 5 | 6 | 5 |
| Haul to construction site | mins | 45 | 90 | 65 | 110 | 57 |
| Unload time | mins | 4.4 | 4.4 | 7.8 | 7.8 | 8.5 |
| Return to plant | mins | 45 | 90 | 65 | 110 | 57 |
| Cycle time | hrs | 1.7 | 3.2 | 2.4 | 3.9 | 2.1 |
| Number trips/truck | no | 4 | 2 | 3 | 2 | 3 |
| Number trucks required | no | 6 | 10 | 4 | 6 | 3 |

## Method 3 - Determining truck resources using EZStrobe simulation modelling

EZStrobe is a general-purpose simulation based on activity cycle diagrams (ACD) and employs a three-phase activity-scanning paradigm. The modelling elements that can be used in EZStrobe, the precedence rules that govern them and their explanation can be found in (Martinez 1998). Activity-scanning models are prepared showing the activities, conditions needed to start and the outcomes of the activities when they end. The activity-scanning model is then represented in an ACD where resources collaborating to achieve a task, idle resources and the links between them representing the flow of resources are shown. The resultant EZStrobe model for the loading, transport and the unloading of the asphalt mix is shown in Figure 1.

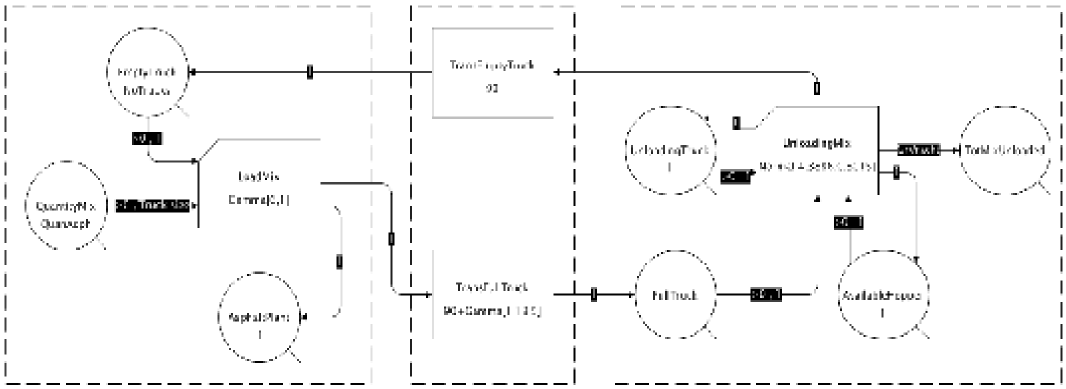

*Figure 1 - EZStrobe model of the loading, transport and unloading of the mix*

The model requires an input of probabilistic durations. The data are analysed to determine the most appropriate statistical distribution for particular tasks, i.e. whether it is random, beta, uniform or any other distribution. The statistical analysis is made possible by firstly, analysing box plots and histograms and secondly, fitting the appropriate distributions. This is important for setting shape parameters for statistical profiles for the duration of activities. Then, as the model simulates, the durations closely mirror the actual fluctuations of the durations (Gowda et al. 1998). The steps followed in developing the input model for these simulation experiments are shown in Figure 2. Note that the chi-square test was used to test if the sample of data came from a population with a specific distribution. The calculated distributions and parameters for the A35-freeway construction site are shown in Table 4. This was repeated for the N18 and Emma Street projects.

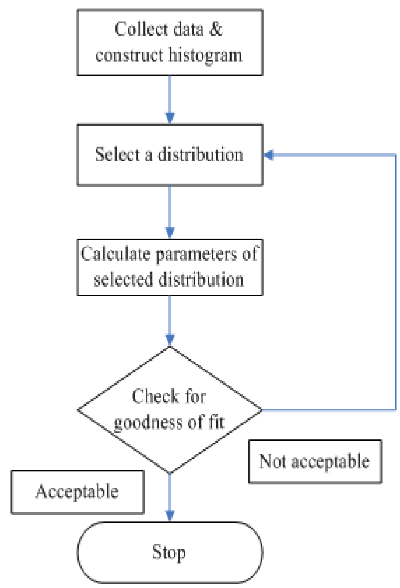


*Figure 2 - Developing an input model for the simulation experiment*

*Table 4 - Statistical distributions and parameters for the A35 project*

| Activity | | Distribution | Parameters | |
|---|---|---|---|---|
| Loading time per truck (mins) | Deventer to A35 | Gamma | $\alpha = 5$ | $\beta = 2$ |
| | Nijkerk to A35 | Gamma | $\alpha = 6$ | $\beta = 1$ |
| Quantity asphalt per truck (tons) | Deventer to A35 | Normal | $\mu = 28.85$ | $\sigma^2 = 3.51$ |
| | Nijkerk to A35 | Normal | $\mu = 30.51$ | $\sigma^2 = 3.59$ |
| Distance & time from plant to site | Deventer to A35 | - | 44km | 45mins |
| | Nijkerk to A35 | - | 106km | 90mins |
| Unloading time per truck (secs) | | Normal | $\mu = 263.31$ | $\sigma^2 = 48.09$ |
| Unloading time per ton of asphalt (mins) | | Normal | $\mu = 0.155$ | $\sigma^2 = 0.034$ |

EZStrobe simulations were run for all five road projects. During the simulation experiments, each time the number of trucks in the system was increased by one. For each project, the model was run a minimum of eight times with fifty runs completed for each simulation. The resultant truck resources required for the Deventer to A35 project is shown in Table 5. Note that the target production for the day is 752 tons. This can be achieved using a minimum number of 8 trucks in the transport cycle. Using the simulation software, the estimated number of trucks required for the various sites are shown in Table 6.

*Table 5 - Extract from the simulation summary for Deventer to the A35*

| No of trucks | Ave. time load mix | Ave. interv. betw. load mix | Ave. time transp. mix | Ave. interv. betw. transp. mix | Ave. time unload mix | Ave. in-terv.un load mix | Ave. wait time at asphalt plant | Ave. wait time at site | Total truck trips | Production (tons) in 8 hr day |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 9.6 | 28.2 | 59.9 | 28.1 | 4.3 | 27.4 | 4.8 | 0.4 | 18.0 | 447.2 |
| 5 | 10.2 | 22.9 | 59.0 | 22.7 | 4.4 | 22.7 | 6.8 | 0.4 | 21.9 | 548.2 |
| 6 | 10.1 | 19.0 | 59.7 | 19.2 | 4.4 | 19.4 | 8.6 | 0.5 | 25.6 | 643.4 |
| 7 | 9.9 | 16.3 | 58.6 | 16.2 | 4.4 | 16.5 | 12.1 | 0.5 | 29.9 | 741.4 |
| 8 | 10.1 | 14.8 | 57.8 | 15.0 | 4.3 | 15.0 | 21.8 | 0.7 | 34.3 | 776.1 |
| 9 | 10.1 | 13.1 | 58.6 | 13.2 | 4.3 | 13.6 | 27.5 | 0.7 | 36.0 | 779.0 |
| 10 | 9.9 | 12.0 | 60.5 | 12.0 | 4.4 | 12.4 | 30.5 | 0.5 | 37.0 | 779.0 |
| 11 | 10.2 | 11.5 | 58.2 | 11.6 | 4.3 | 11.6 | 36.2 | 0.7 | 38.0 | 779.0 |

*Table 6 - Number of trucks required based on the EZStrobe simulations*

| | Deventer to A35 | Nijkerk to A35 | Deventer to N18 | Nijkerk to N18 | Deventer to Emma |
|---|---|---|---|---|---|
| Number trucks required | 8 | 13 | 5 | 10 | 5 |

## ANALYSIS AND RESULTS

A comparison of the truck resources required using three different methods is shown in Table 7. Assuming the focus of the contractor is on productivity and thus trying to achieve the target production within the 8-hour day, then two issues are apparent. On the one hand, the contractor appears to consistently overestimate the number of trucks required for the shorter trips from the Deventer asphalt plant. Whilst an overestimation ensures that work will probably be completed within the 8-hour day, it most likely results in unnecessary increased costs. On the other hand, the contractor has underestimated the number of trucks required for the trip from the Nijkerk asphalt plant to the A35 project perhaps resulting in extended working hours and thereby incurring an increase in labour, plant and other costs related to working beyond normal hours.

*Table 7 - Comparison of trucks resources required*

| Road | Distance from plant to site (km) | | Ave. travel time (mins) | Actual trucks allocated | Fleet-demand method | NHI Method | EZStrobe simulations |
|---|---|---|---|---|---|---|---|
| A35 | Deventer to A35 | 44 | 45 | 9 | 7 | 6 | 8 |
| | Nijkerk to A35 | 106 | 90 | 9 | 11 | 10 | 13 |
| N18 | Deventer to N18 | 58 | 65 | 8 | 5 | 4 | 5 |
| | Nijkerk to N18 | 120 | 110 | 8 | 7 | 6 | 6 |
| Emma | Deventer to Em. | 62 | 57 | 5 | 4 | 3 | 4 |

## CONCLUSIONS

The algebraic fleet-demand and NHI calculations are similar in method and result. Both calculations can be extended and made more useful by calculating a desired paver speed for asphalt laydown operations, based on the actual number of trucks assigned to the site. This additional parameter is particularly advantageous in that there is an attempt to match the number of trucks being used in the logistics cycle and the headways between truck arrivals with the speed of the paver. It is important that there be a constant supply of asphalt to the paver. The paver operator is then able to adjust the speed of the paver given changes in the supply of asphalt to the construction site. The fleet-demand and NHI methods provide the contractor with a rough estimate of the minimum number of trucks that could be used for a project given the target production for the day, the number of working hours and an approximation of the cycle times. However, both methods do not take into account the stochastic effect inherent in construction. This stochastic effect can be modelled using EZStrobe. As the model simulates, the durations closely mirror the actual fluctuations of the durations. This provides additional insights into the headways between truck arrivals, waiting times at the plant and site, and the time taken for unloading the mix. These parameters are important in ensuring that there is a constant supply of asphalt to the paver. In general, all three methods provide the planner with more accurate means of determining the truck resources required for the transport of asphalt from the plant to the site. Despite the differing travel distances and therefore cycle times, it appears that the planner has not considered them in determining truck resource requirements. In addition, it appears that the planner has neglected to take into account the effect of work zones on the construction site. Moreover, all three methods discussed in this paper neglect to take into account the effect of work zones on road construction sites. A number of researchers have studied the effects of traffic flow rates and lane closures on asphalt pavement productivity (Jiang 2003, Nassar et al. 2003). These work zones and lane closures not only cause traffic delays to motorists, but also affect productivity by impeding the asphalt delivery trucks' access to the construction site. These delays would result in excess travel time for trucks to deliver asphalt from the plant to the construction site. As a consequence, productivity and construction cost would be affected negatively due to the longer cycle time of the material delivery vehicles.

## THE WAY FORWARD

Improving the asphalt paving process requires an examination of the whole process from the manufacture of the asphalt, to transport and final construction of the asphalt pavement. This research group proposes an action research strategy involving planners, operators and researchers in addressing the apparent mismatch between current work methods and the on-site operational strategies. The next step in this ongoing research project would be to confront the planners with explicit process information relating to the logistics phase and to jointly work towards improvements. A smoother operation and a higher quality of pavement may prevent potential problems relating to stop-and-go operations such as unnecessary construction joints, inconsistent material density and low pavement smoothness. The unravelling and confronting of the practitioners view is expected to lead to improved control during the asphalt paving process and consequently to improved product and process performance. This joint strategy may lead to changes in operational behaviour. The action research approach provides opportunities for developing a framework to capture the operational characteristics of the asphalt paving process in a more holistic manner. It diverts from previous process modelling studies where key role players have been left out of the process. Latham as cited in (Blockley et al. 2000) observed that “there is an acceptance that a greater interdisciplinary approach is necessary, without losing the expertise of individual professions.” He recognised that all concerned with construction are interdependent and need to behave as a team. Blockley and Godfrey (2000) also argue that “we need to have a whole new view of process” and in order “to do that we need to include factors that are particularly needed when co-operation between people is important”. The key issue here is that the planners need to be involved in, and take responsibility for the process. They are in fact largely responsible for the success of the asphalt paving process.

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