S.M.A.R.T – Project, Kuala Lumpur

Tunnelling with Hydro - Shield

Analysis of the Logistics

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Abstract

The topic of logistics, which stands for the efficient and effective design and management of material flows, gains more and more importance. A well-organized and thought-out logistic concept is vital to support and guarantee an efficient and therewith cost saving construction process. On tunnelling sites, the scheduling and coordination of the material flows is essential to ensure smooth operations and to avoid cost consuming interruptions. If the required materials are not on schedule and accurate in quantity and quality and if the disposal of the excavated materials is not sufficient, the two main tunnelling processes of advance and ring building cannot run continuously. The logistic of the S.M.A.R.T-Project has to be designed for the supply of e.g. 9300 tons of bentonite for the bentonite slurry, more than 28000 segments for the concrete lining and 131000 tons of grout. The tunnelling process of the S.M.A.R.T.-Project is heavily dependent of the separation plant and the most worrying bottleneck is the disposal of the arising excavated material of in total 740000 m^3.

1 S.M.A.R.T – Project

1.1 The Tunnelling Project

Kuala Lumpur has experienced a quick growth during recent years, which has led to exceeding capacities of roads and rivers and therewith to regular flooding of riverbanks. Hence, the government tendered the RM 2 billion (app. 500 Mio. US$) "*Storm Water Management and Road Tunnel Project*", short S.M.A.R.T. Project, designed to divert storm water and to reroute traffic away from the inner city.

The tunnel has an overall length of 9700 m, incorporating 2800 m motorway, carrying two lanes in each direction on vertically separated road decks.

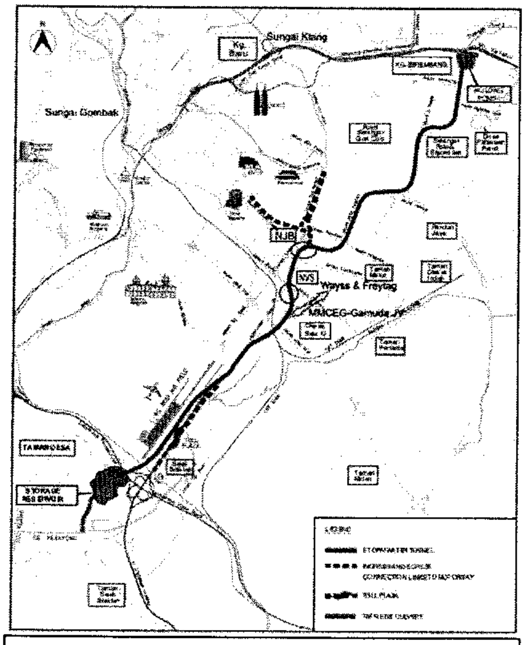


Figure 1: Alignment of the S.M.A.R.T – Tunnel [Ministry of Agriculture, Malaysia, Department Irrigation and Drainage/ Flood Mitigation, Internet portal www.agrolink.mao.my,

During moderate storms, the bottom section of the tunnel will channel excess water without stopping the traffic flow.

In cases of exceptionally severe storms, all traffic will be evacuated and automatic watertight gates opened to allow floodwater flow. The tunnel has a combined storage capacity of 3 million-m^3 water. Ponds and tunnel will attenuate the flood flows and regulate the discharge into the river. [New Sunday Times, Focus, 19.10.03, Kuala Lumpur, Malaysia]

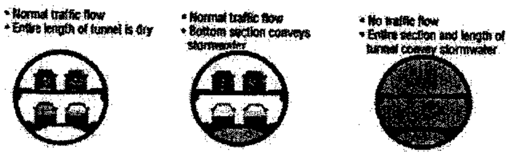


Figure 2: Tunnel Operation Modes [New Sunday Times, Focus, 19.10.03, Kuala Lumpur, Malaysia]

1.2 Data of the Tunnelling Project

Table 1 below shows the main facts of the S.M.A.R.T – Project, North Drive, which is constructed by Wayss & Freytag (M) SDN. BHD.

Description	**Specification**
Bore Drive 1: Road Tunnel from NVS to NJB	700 m
Bore Drive 2: Storm Water Tunnel from NJB to NIS	4 550 m
Cross Passages	2 nos.
Inclination	0.136 %
Inner - Diameter	11.830 m
Length of Rings	1.700 m
Thickness of Rings	0.500 m
Min. Radius of Curvature	250 m
Taper of Rings	110 mm
Tunnel Excavation	720 000 m^3
Rings	3 117 nos.
Segments (9 per ring)	28 053 nos.
Tolerance Diameter Ring	+ / - 0.6 % deviation
Steps between two Rings	Maximum 10 mm

Table 1: Technical Data North Tunnel Drive

1.3 The Tunnel Boring Machine

The following Table 2 gives a short summary of the technical data of the TBM used for the S.M.A.R.T. Project, North Drive.

Description	**Specification**
TBM Manufacture	Herrenknecht AG
Type	Mix – Shield
Front Shield Diameter	13.210 m (without hard facing)
Length / Weight of TBM	12.000 m / 1 500 tons
Length / Weight of Backup	53.000 m / 1 000 tons
Min. Radius of Curvature	200 m (TBM + Backup)
Thrust Cylinders	16 triple jacks (2.500 m)
Unit Thrust Force	210 tons / cylinder
Total Thrust Force	10 100 tons at 315 bar
Maximum Advance Speed	5 cm / min
Cutter Head Rotation Speed	0 – 3 rpm
Max. Break out Torque	31 500 kNm
Max. Operating Pressure	300 bar
Installed Electric Power	4 000 kW

Table 2: Technical Data TBM

1.4 Specific Restrictions

Besides the data of the tunnelling project and the TBM, specific local restrictions concerning transportation and traffic have to be considered in any logistic concept. Kuala Lumpur suffers under heavy air pollution, which is caused by a huge amount of cars in the city, mostly heavy traffic jams during rush – hours and in addition to that a lack of regulation regarding emissions.

As a reaction to this, the government issued the ordinance that no heavy traffic, such as trucks or lorries, is allowed to enter the streets within the peak traffic hours. This means that from 7.00 am to 9.30 am and from 4.00 pm to 6.00 pm transport from or to the site is not possible.

2 Elements of Logistic on Site

Logistics is a special management approach to develop, design, coordinate and realize material flows effectively and efficiently regarding both processes within (intraplant) and beyond (interplant) a company.
This reveals that logistics on construction sites spreads over the following different parts of the complete production process, which are shown in Figure 3.

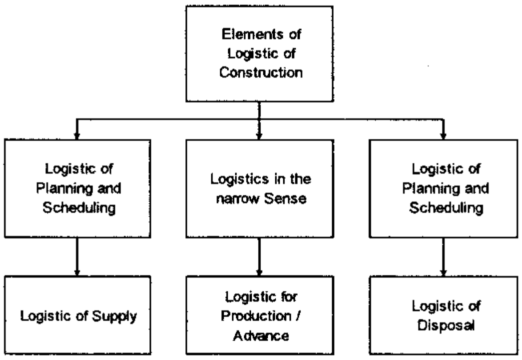


Figure 3: Elements of Logistics on Site

In the following, the different elements are theoretically explained and afterwards, the most important material flows of the specific process for the S.M.A.R.T – Project are roughly described and characterized.

2.1 Logistic of Supply

The logistic of supply includes all needed activities to supply all consumables required for the production process.
It is vitally important that the supplies are on schedule, exact in amount and quality. The main stock on the supplier plant has to be big enough to absorb variations of advance e.g. times without any delivery to site (shutdown of TBM). In contrast to that, the temporary stock on site has to be big enough to absorb high progress and high delivery rates (high performance of TBM).

As the requirement varies at sporadic intervals, which are determined short-term by the present consumption of materials and long-term by the scheduled and extrapolated consumption, the logistic of supply has to be planned with an adequate buffer.

2.1.1 Bentonite

As there are no mining areas in Malaysia, the bentonite for the S.M.A.R.T – Project is delivered to Malaysia from India. It is stored at the supplier's plant and delivered to site in charges of minimum 20 tons. On site there are two silos containing 90 m³ bulk bentonite each. With an average consumption of 12 kg/m³ excavated material and a medium advance of 10 rings/day, the maximum consumption of bulk bentonite for the project can be scheduled to 17.280 to/day. The complete consumption of bentonite can be calculated to 9300 tons.

2.1.2 Pre-Cast Concrete Segments

The lining of the tunnel is built of 9 pre-cast concrete segments including the keystone. As, in this project, the keystone must obtain a position above the spring line, there are two different types of rings, left and right hand tapered rings. If the ring is built always by starting with the bottom segment, there would be according to the possible keystone positions for each type of ring 8 different required loading sequences to the segment feeder. As this might cause breaks, shutdowns or irritations due to a false supply to site or to the TBM, another ring building process is applied. This process starts, regardless of the keystone position and the type of ring, each time with segment D, which would be with the keystone position at 0 gon the bottom segment. The next segments are all segments on the left side for a left hand tapered ring resp. on the right side for a right hand tapered ring. Then, the process continues with all segments on the

other side of segment D. Finally, the process is finished with the keystone; segment K.
This leads to only two different loading and delivery sequences of the segments. Besides the simplification of the logistics, this ring building process is time saving in a tunnel with such a large diameter, as the workers do not have to change the sides after each built in segment.
Due to the local restrictions the segments can only be delivered to site during night – time. Therefore, the stock on site should cover an average consumption of 10 rings/day for 1 ½ days.
The complete tunnel is built of 3100 rings, which are 27900 segments.

2.1.3 Grout

The grout batching plant is located on the site yard of NJB. During "Bore Drive 1" from NVS to NJB, the grout will be be transported by mixer trucks of 6.0 m^3 capacity using the normal road network. During "Bore Drive 2" from NJB to NIS, the grout will be either pumped directly into the grout car or transported by mixer trucks within the site yard.
With a maximum over cut of 35 mm and therefore a maximum consumption of 17.646 m^3 grout/ring, and a average advance of 10 rings/day, the maximum consumption for the project can be scheduled to 244.370 to/day. The complete consumption of grout can be calculated to 131000 tons.

2.1.4 Logistic for Excavation / Advance

The logistic for excavation / advance is conceived to guarantee at any time all materials to render the tunnelling process possible. The advance itself, following prevailing opinion, is not part of the logistic concept. It is rather the overall limitation, on which the logistic concept is applied.
Regarding the logistic of production, the most important condition is to avoid any shutdown of the TBM caused by bottlenecks in the supply chains.
Whereas the production itself is a more or less continuous process, the supply of required materials is split into two parts occurring at regular intervals.
First, there is the loading process from the temporary stock on site to the transportation system in the shaft. This can be called the vertical transport. As a second or horizontal part, there is the actual supply by the transportation system to the working face.
The design of these two processes, loading and transportation, is in most cases a balance between highest performance and an adequacy of resources in terms of finance and utilization ratio.

2.1.5 Tower Crane

The tower crane performs the tasks of horizontal transportation on the surface and of vertical transportation to the railway system in the tunnel.
The horizontal transportation includes unloading processes from trucks, changing positions of materials within the storage area and supporting construction works.
The vertical transportation means mainly the loading process of the train in the shaft with all required materials.
The horizontal transportation on the surface has to be finished, while the train drives to the TBM, is unloaded at the TBM and finally drives back to the shaft.

2.1.6 Railway System

The design of the train operation is determined of several restrictions.
First, the train has to arrive at the TBM a certain time before the advance itself starts. The lead-time depends on the time, which is required to provide at the TBM a secure supply of grout during advance.
Then, the driving time of the train from the shaft to the TBM and back has to be as short as possible. Therefore, the supply of grout,

segments and further consumables can be flexible and rapidly adapted to modified requirements of the tunneling process. This might be necessary if the advance rate and the amount of required construction materials increase.

Finally, the railway system should include as few different trains as possible. The more trains there are the more required installations such as switches and rails there are. Cost and required space as well as the demands on the accomplishment of the logistic concept increase with the amount of trains.

2.2 Logistic of Disposal

The third part of logistics on site is the logistic of disposal, which includes removal and waste management of all residual building materials.

The accumulating masses are only determined by the production progress. Regarding the amount of materials to stock and the intervals in which the materials are removed from site, the process is additionally determined by local transportation conditions.

Generally, the temporary dumping area on site has to be big enough to accommodate the continuously accumulating masses as long as the disposal cannot take place.

2.2.1 Excavated Materials

According to the scheduled advance of 10 rings/day and the geological profile of carstic limestone with soft soil area, the maximum arising masses can be calculated to 1382.400 m^3-bulk/day. In total, a volume of 740000 m^3 excavated material arises.

A condition for the timely process of disposal is that the excavated material of one day is disposed within the same day. Therefore, the temporary dumping area can absorb peaks within the output of the separation plant or days with a disposal of excavated materials less than necessary.

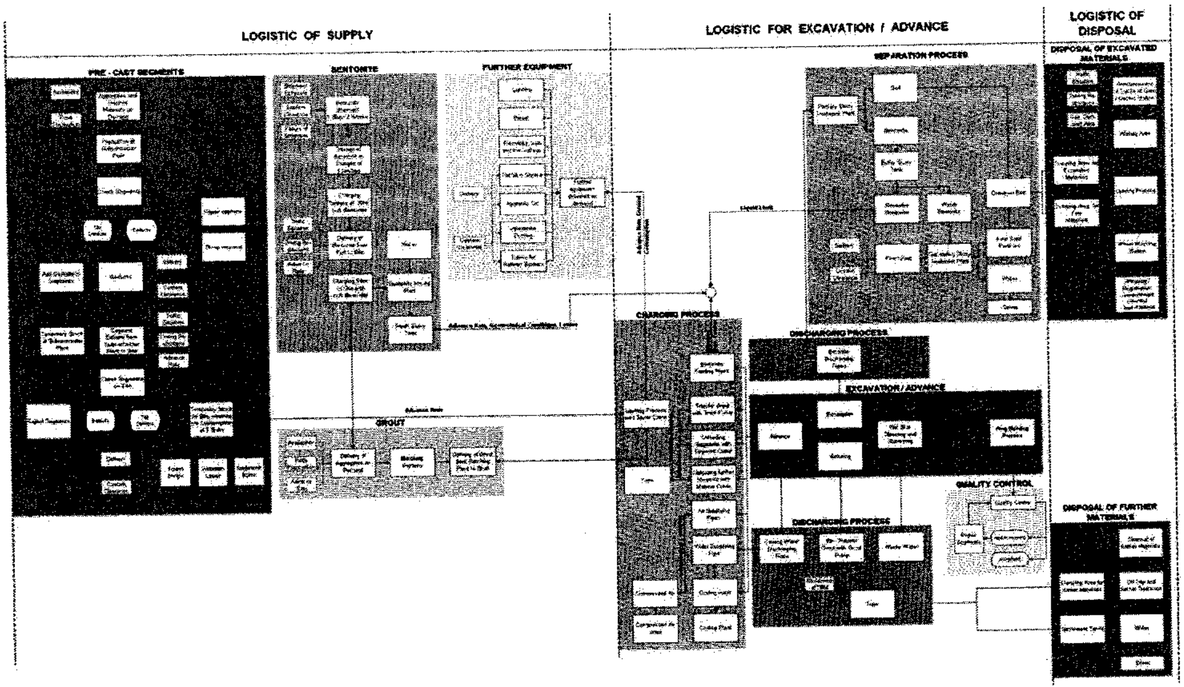
The cycle of the earth – moving machine for one loading process can be calculated to 1.00 min / dump. This leads to the result, that for the scheduled average advance of 10 rings/day, 325 trucks are required for disposing the materials.

To be able to manage such a high amount of excavated materials and therewith such heavy site traffic, the process of disposal must take place constantly during day and night. The required site installation must be well designed and organized to accommodate all required trucks without disturbing any other required process.

3 Logistic Concept

The designed logistic concept should consider all processes of the logistics. However, the design of the logistic concept cannot eliminate all interferences or avoid all bottlenecks within or between the different processes. It only can help to verify the bottlenecks and therefore, to be aware of the sensual or critical processes. Nevertheless, the logistic concept should provide solutions for the main bottlenecks.

The complete flow chart of the required logistics is shown below. With the aid of the flow chart, the main bottlenecks can be specified, analysed and possible solutions can be developed.



3.1 Bottlenecks and possible Solutions

3.1.1 Production of Concrete Segments

General Bottleneck

The quality of the tunnel is highly dependent on the quality of the pre-cast concrete segments.

First, all segments, which are installed inside the tunnel, have to be of a 28-day strength. This is normally guaranteed by installing only those segments with a casting date, which is at least 28-days old. Theoretically, the 28-day strength can be reached earlier.

Second, the installed ring has to transfer the advance and thrust ram forces. The more repairs on a segment were made, the higher the risk for spallings, cracks and leakages.

General Solution

For both mentioned demands to the segments, the production and treatment of the segment is vital.

The only possibility to ensure the quality of all required segments, is to schedule, supervise and track the production thoroughly and continuously from the very beginning to the very end. Doing so, might avoid endless, annoying and cost intensive repairs after installation of the segments.

3.1.2 Excavation – Separation Plant

The excavation and the separation plant are heavily dependant on each other. This means that, without excavation, the separation plant does not have any input and that, without a functional separation plant, the excavation and therewith the advance cannot be started. Thus, in the lead of any analysis of the site installation in terms of possible bottlenecks, the determine process, advance or separation, has to be found out.

The required time for separation resp. the mass flow to the separation plant is highly dependant on the geometry of the working chamber of the TBM. Suction pipe, rake and crusher and the therewith caused hydraulical conditions influence the required discharging rate and the amount of discharged material within the slurry.

Experiences of former projects with hydro-shields in similar geological conditions and a similar ratio of the flow rate of the separation plant to that of the working face have shown that the hydraulic transportation of excavated materials rarely exceeds 250 kg/m^3 - suspension. [Value of experience, Michael Strässer, W&F, HNL ITI, April 2004]

This means that for the S.M.A.R.T. – Project, the design of the separation plant allows a maximum advance rate of the TBM that is only slightly higher as the scheduled average advance rate.

The following chapters illustrate the main bottlenecks for NVS and NJB and possible solutions for the scheduled average advance rate of 10 rings/day.

3.1.3 Separation Plant – Disposal

Bottleneck at NVS

325 trucks are required for the disposal of the excavated materials of one day.

All these trucks have to leave the site yard through one exit by passing first the wheel washing station and then the weighing station. Thus, the loading process at the muck pit might be determined by the re – entering of the trucks to the public road.

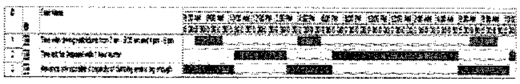
Due to the specific local restrictions, trucks are not allowed to drive within the city of Kuala Lumpur for 4 ½ hours a day. This means, that they cannot re – enter to the public road during these hours. Assuming, that the trucks will not reach the site 1 hour before and after the driving restriction, the loading process has to stop for 8 ½ hours a day. During that time, additional parking space for the trucks within the site yard is required.

Solution

In case of jams within the site yard, caused by the re-entering to the public road, a temporary driving round road can complement the drive through site road. As long as this is only a temporary solution, it might be acceptable, that these trucks will not pass a wheel washing and weighing station. As soon as this solution will be set up as a permanent solution, a second wheel washing and weighing station must be installed.

However, in any situation, it must be a priority to sustain the normal site operation and to avoid that the queuing and waiting trucks determine and disturb the normal site operation.

Gantt Chart 1 shows the time schedule for the site traffic and the critical hours for the advance. During these hours, an advance is only possible if the dumping area has still enough capacity to accommodate the excavated materials.



Gantt Chart 1: Time Schedule Site Traffic

3.1.4 Advance – Transports

Bottleneck at NJB

The scheduled average advance of the TBM leads to a huge amount of required materials, which have to be supplied by trucks, all entering the site yard of NJB. The required materials include the grout transportation within the site yard as well as the supply of grout aggregates, segments and further consumables.

All required materials, delivered during night and day time have to be unloaded from trucks during the night shift, while the tower crane still has to load the train and assist other works on site.

Solution

The huge amount of upcoming site traffic requires a well-organized site traffic management system including in advance announcement of trucks, scheduled arriving times and a fully functional control of compliance with the site traffic management system. Otherwise, the utilization of site road and tower crane will highly oscillate between full to capacity and quiet.

Moreover, this will lead to interruptions of the normal site operation and will end up in even more difficulties especially during daytime, as there is not enough space on site to handle a huge amount of waiting and uncoordinated manoeuvring trucks.

4 Résumé and Reflection

As a conclusion of this research, it can be said, that in order to efficiently run the site and the associated construction processes, it is essential to plan, implement and manage a structured logistic program.

First, an analysis of logistics is required, to verify the different material flows. These flows should be analyzed with the aid of supply chain management. Therefore, all independencies and critical points within the specific flows can be determined and worked out.

A logistic concept has to be designed to combine all different material flows and to work out possible interdependencies and all potential bottlenecks. Using a logistic concept is necessary in order to verify not only bottlenecks but also the accessory crucial position of the material flow, on which a proposed possible solution should have an impact. Thus, difficulties resulting out of bottlenecks can be recognized as soon as they are about to emerge and developed possible solutions can be implemented.

Without a logistic concept, it might happen, that bottlenecks are not verified and solutions might be taken as soon as their effects are arising, which does not solve the actual cause but only the direct effects. This might lead to even more bottlenecks or at least not to a permanently working solution. This means a loss of ability to act and leads to the passive position of reacting.

However, considering logistic solutions only in the course of operations scheduling is not sufficient, because this would only roughly draw up possible solutions, which could not be worked out properly.

During the whole project, the designed logistic concept has to be revised continuously and the logistic procedures have to be monitored constantly in terms of practicability, functionality and the desired effects.
Thus, bottlenecks, which were not reflected during the design of the logistic concept, can be taken into consideration as soon as they become apparent. The logistic procedures, such as traffic management systems or requisition processes, can be adapted step by step according to the required demands. Only by this, the logistic concept can bring out an effort in terms of saving costs, and efficient and effective work on site.

The logistic analysis should not be confined to the analysis of the expected material flows, but should be continued at the end of the project. The occurred bottlenecks should be evaluated and analyzed in terms of frequencies, reasons and effects. Thus, the identified interdependencies, critical points and the accessory solutions could be possibly considered in future projects. Therefore, the amount of not identified bottlenecks, which are time and cost consuming, can be minimized and the logistic concepts of future projects can be optimized.