TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

ANNA SOBOTKA, KAZIMIERZ LINCZOWSKI*

ANALYSIS OF LOGISTICS FOR CONSTRUCTION SITE SUPPLY WITH REINFORCING STEEL

ANALIZA LOGISTYKI ZAOPATRZENIA BUDOWY W STAL ZBROJENIOWĄ

A b s t r a c t

Owing to the numerous advantages of this technology, the continuous development of monolithic constructions have been made possible. The complexity of structures using this technology have been made possible thanks to the use of modern shuttering, the production of high quality concrete mixes carried out by professional concrete-mixing plants and efficient logistics supporting investment projects. The weakest element in organisation of these works is the supply of reinforcing steel, an expensive resource which is consumed in large quantities thus requiring extensive logistical planning. On the basis of their professional experience, the authors of this paper present their analysis of logistical models for supplying construction sites with reinforcing steel. Using the AHP method, they carry out a multi criteria evaluation of possible supply systems. Then, applying decision inventory theory models, they determine control quantities leading to logistic system optimisation according to the selected criteria.

Keywords: reinforcement steel, logistics of supplies, models, decisions

S t r e s z c z e n i e

Obserwowany jest ciągły rozwój budownictwa monolitycznego, dzięki licznym zaletom tej technologii. Poziom wykonawstwa obiektów w tej technologii jest wysoki dzięki dostępności nowoczesnych deskowań, wytwarzaniu mieszanek betonowych wysokiej jakości przez profesjonalne betonownie i sprawnej logistyce obsługującej inwestycje. Najsłabszym ogniwem organizacji tych robót jest zaopatrzenie w stal zbrojeniową, którą zużywa się w dużych ilościach i jest strategicznym oraz drogim zasobem. Autorzy na bazie swoich doświadczeń zawodowych prezentują w artykule analizę modeli logistyki zaopatrzenia budowy w stal zbrojeniową. Za pomocą metody AHP przeprowadzają ocenę wielokryterialną możliwych systemów zaopatrzenia. Następnie, wykorzystując modele decyzyjne teorii zapasów, określą wielkości sterujące, prowadzące do optymalizacji systemu logistycznego wg wybranych kryteriów.

Słowa kluczowe: stal zbrojeniowa, logistyka zaopatrzenia, modele, decyzje

* Prof. D.Sc. Ph.D. Eng. Anna Sobotka, M.Sc. Eng. Kazimierz Linczowski, Department of Geomechanics, Civil Engineering and Geotechnics, Faculty of Mining and Geoengineering, AGH University of Science and Technology.

1. Introduction

The building of modern structures requires the delivery of considerable quantities of building products and other resources to construction site. Among other things, the logistics of supplies affects the prompt completion of construction works as well as the cost and quality of the project components, and in particular safety of workers. The various logistical methods, with particular reference to expensive materials ordered in large quantities, needs to be controlled effectively.

In this article, the authors discuss supplying reinforcing steel for the construction of apartment buildings. Steel being a basic material used for erecting buildings and volumetric structures have a key impact on the basic works planned in the critical path schedule, and thus on the completion date of the project. On the basis of their professional experience, the authors present their analysis of logistical models for supplying the construction site with reinforcing steel, proposing a systematic approach to the logistical process of steel supply to a construction site. In the first stage, it involves carrying out a multi criteria evaluation of possible supply systems using the AHP method [1, 7, 8, 10]. This method allows for the best logistical service type. Then, applying the decision model of inventory theory, they determine control quantities leading to a logistical optimisation system carried out according to the selected criteria. These are delivery dates and volumes coordinated with the construction works schedule. The results obtained provide the basis for making decisions, which allow for a reduction of logistic costs.

2. Organisation of logistics for construction site supply with reinforcing steel

In the case of buildings constructed using monolithic or improved conventional technology, the main aspects of supplying building products to the construction site are the limited supply of reinforcing steel or small-sized components (hollow bricks/blocks of different types). Due to the high diversity of hollow bricks and blocks, the authors renounce describing that resource as being available, proportionally cheap and easy to replace. Producing reinforced concrete elements on a construction site involves form work fitting using the wide range of systems offered by manufacturers, prior to commencement of works brought to the construction site. After the installation of the reinforcement in the shuttering, the concrete mix is poured, this usually being brought to site directly from a concrete-mixing plant and pumped into the form work. In the case of resources, the logistical issue first refers to the selection of a good manufacturer, who will guarantee good quality material, competitive prices, suitable payment conditions and efficient transportation, etc. The shuttering set required is delivered before the commencement of works, and the concrete mix is delivered via the *Just-in-time* system. Therefore, the only logistical benefit is to seek better solutions for the supply of reinforcing steel and in particular reduction of costs. Due to design diversity and required assortment of steel to be built into the structure and its current market cost, reinforcing steel is a material, which may affect the investment project's implementation not only from a logistical, but also financial point of view.

As regards organization, the most convenient solution for reinforcing steel deliveries could be to store complete or partial steel demand – in advance of one full constructional element on site – consuming the steel as required. However, this is economically unjustified, as this would mean the need to freeze company financial means. Figure 1 shows organisation of reinforcing steel deliveries to construction site at various conditions.

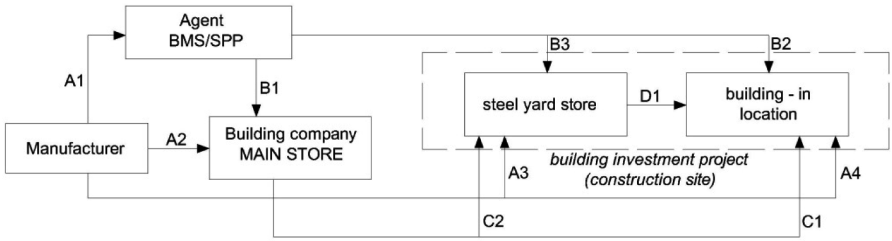

Fig. 1. Organisation of logistic chains for reinforcing steel deliveries to its building-in location

Chains starting with letter A indicate delivery of a specific assortment, amounting to a full transport of reinforcing steel (24 tons, transported units 12 metres in length). This amount constitutes the logistical minimum in order for a target buyer to get a competitive price from the manufacturer. Therefore, it is frequent building company practice to buy steel through agents (chains starting with letter B). Typical agents in reinforcing steel sales are building materials stores (BMS). The advantages resulting from shopping at BMS include:

1) possibility of satisfying diversified construction site demand for steel at advantageous conditions as regards prices, assortment and quantity – benefiting from scale (mass) effects of BMS purchases from manufacturer;
2) convenient delivery. The building company implements investment projects in various locations and at various distances from the steel manufacturer's plant. During logistical planning, the company possessing a contract with one or more BMS's agrees upon a delivered price to the specific construction site. As a result of this, the building company does not incur extra transportation costs (for orders covering steel delivery for the entire investment project);
3) limited storage. A specific amount of steel is delivered to the construction site, directly to the location of its incorporation into an erected structure (division of the whole order into parts satisfying logistic minimum of BMS). As a result of this, building company does not have to store material on site and therefore does not incur any extra costs. Storing steel on a construction site involves transportation and hoisting costs within construction site. In the case of steel characterised by disadvantageous dimensions for transportation (packaging in bundles, considerable weight of individual bundles)which is expensive because it requires hoisting crane or tower crane to be operated at builder's yard.

BMS's deliver primarily straight steel, and the proper shapes and lengths for building-in are to be prepared on construction site. In the case of complicated design solutions with unusual bending of reinforcing shapes and/or using diameters exceeding Ø16 (frequently Ø20, Ø32 or higher) the full working of straight steel on site is unprofitable, and sometimes impossible due to the limitations of mobile shears and mobile bending machines for steel. In these cases, the third option is to use the steel suppliers selection, that is the steel prefabrication plant (SPP). SPP performs work on large reinforcing steel diameters, including both the cutting and bending of elements/shapes (plants of this type are equipped with stationary machines allowing production of steel shapes of any diameter). Reinforcement made at SPP is characterised by good quality, accurate workmanship and repeatability of shapes, which are more difficult to obtain on a construction site due to: weather conditions, workers' fatigue, bending inaccuracy due to rushing (steel fixers' gangs are paid for built-in steel tonnage), low quality of manual bending machines (this is very important in production of e.g. stirrups), etc. Reinforcing steel supply from SPP increases reinforcement costs, but it speeds up the production process, reduces labour consumption and labour costs for steel building-in into the structure, and often turns out to be the only possibility of incorporating designed reinforcement into an erected structure. In the case of steel deliveries by SPP, financial and transport-related solutions are similar to those applied by BMS. A frequent practice of building companies is to buy steel from BMS and SPP, and at the same time from manufacturer (Fig. 1).

The practice shows that due to fluctuations in steel prices, building companies implementing many investment projects in a given accounting period purchase steel in higher quantities and deliver it to the main store. This requires possessing free funds and usually means freezing capital over a longer period. Capital freezing may be determined according to cost estimates, because when signing contracts, building companies estimate prices of steel at the moment of signing the contract. Storing the require volume of steel avoids any unpleasant surprises in form of a sudden increase in the price of steel, but also means lost benefits in case of drop in steel prices. When a building company decides to store reinforcing steel in its main store, it has an opportunity to replenish steel stocks at individual construction sites (C chains). D chain indicates in-house transportation within construction site area of spatial reinforcement components assembled in a steel yard.

In most cases reinforcing steel is stored in the form of straight steel. The storing of bent steel is limited exclusively to specific, planned investment project. Assortments of this type cannot be treated as a reserve or long-term investment.

3. The method used to support logistic decisions of reinforcement supply

The authors suggest a two-stage planning of logistic support for reinforcement works while building reinforced concrete structures using improved conventional methods at a construction site (involving selection of logistic chain type/delivery type), and determining the parameters of the logistical processes, that is first of all: delivery dates and optimal size of delivery batch due to the criterion of minimising costs of logistics (logistic processes/ support). The first stage involves an analysis of structure documentation and identification of external and internal logistic determinants, which directly affect the selection of the support model type using the AHP method [1, 7, 8, 10]. The second stage involves the acceptance of an appropriate model of inventory theory and determination of optimal logistic decision variables minimising logistic costs [4, 5, 6, 8].

3.1. The stage of selecting the type of logistic model for supply

The authors have carried out hierarchic analysis for reinforcing steel deliveries. Three models presenting the types of delivered assortments have been defined. Model I involves a delivery of steel from the manufacturer or through a building material store. Designed reinforcement is prepared for building-in at the construction site (one-type assortment: straight steel, transport length). Model II involves delivery of steel exclusively by the steel prefabrication plant – both steel shapes and straight steel of designed lengths. Model III involves delivery of steel from all suppliers depending on demand at the construction site or steel availability from individual suppliers.

The following characteristics of the first and second degree (Table 1) have been used for the purposes of evaluating the models above by way of the AHP multi criteria analysis. In order to carry out multi criteria analysis, the authors assumed the scale of comparative rating from 1 – for equivalent characteristics to 5 – for the most important characteristics. Since computational algorithms in the AHP method are presented in literature on the subject [1, 7, 8, 10], the authors show computed weights for first degree characteristics in Table 1.

Table 1

Comparison of computed values – characteristics of reinforcing steel delivery models

Model	Advancement of works 0.35*		Delivery type 0.13*			Payment 0.45*		Supplier 0.07*		Rating
	Quality 0.33**	Efficiency 0.67**	All 0.11**	In stages 0.26**	In stages with reserve 0.63**	Purchase costs 0.25**	Payment date 0.75**	Manufacturer 0.33**	Agent 0.67**	
I	0.10	0.11	0.10	0.10	0.11	0.54	0.33	0.60	0.14	0.24
II	0.62	0.58	0.67	0.62	0.58	0.16	0.33	0.20	0.43	0.17
III	0.28	0.31	0.23	0.28	0.31	0.30	0.33	0.20	0.43	0.28

* weights of the first degree characteristics, ** weights of the second degree characteristics

According to completed multi criteria analysis, the most advantageous model of reinforcing steel deliveries is model III (rating 0.28) – mixed assortment: straight steel and prefabricated steel, any supplier.

It should be emphasised that the final result of the analysis above was dependent on the planner's assumptions regarding phenomena, which affects the values of the characteristics of the models considered in a given time and for given building and market conditions.

3.2. Optimising calculation – selection of decision variables

Optimisation of logistic systems (support) for procurement of building undertakings is a complicated task. A building investment project is a special product, and its progress is not fully predictable (in particular regarding earth and foundation works). Model selection, applications for optimising calculations and the implementation of results is not an easy or conventional task.

The literature presents two main groups of stock control models: deterministic and probabilistic. Deterministic models include: the graphical method for determining stock volume, the analytical-graphical method for determining stock volume, taking discounts into account, the optimal order size model, the no-stock model, the dynamic stock control model, the *Just – in – time* (JIT) system, etc. Probabilistic models include: the buffer stock model, the cyclic stock inspection model, the central store simulation model for determining stock volume with two unknowns, the simulation model for determining stock volume with three unknowns, the no-stock model with a known probability, the probabilistic dynamic stock control model and the system of complementary orders, etc.

Not all stock control models and methods can be used in the building industry. According to [4, 5] and experience of authors the most appropriate options are: the graphical method for determining stock volume, the analytical-graphical method for determining stock volume, the buffer stock model, and simulation models for determining stock volume with two and with three unknowns.

According to the authors, the most advantageous stock control model is the deterministic JIT system (no stock, perfect synchronisation of works with deliveries, etc.). Unfortunately, in practice building companies are unable to satisfy all of the objectives of the mentioned system. Delivering concrete mix in the JIT system does not provide a positive results in the case of all resources needed to complete building undertaking.

Reinforcing steel is one of the resources, which fail to satisfy JIT system objectives. It should be noted that even if we take the selected multi criteria analysis, the most elastic model of reinforcing steel deliveries (model III) – supplied reinforcement requires final working before being incorporated in the structure (this will primarily involve construction of spatial elements including beams, poles, etc.).

In order to illustrate an application of logistic support planning that minimises the total logistical costs for steel supply, it is assumed that in the construction of certain multi-storey apartment building, built using improved conventional technology, logistic support will be provided according to model II. Due to various (including practical) reasons, reinforcing

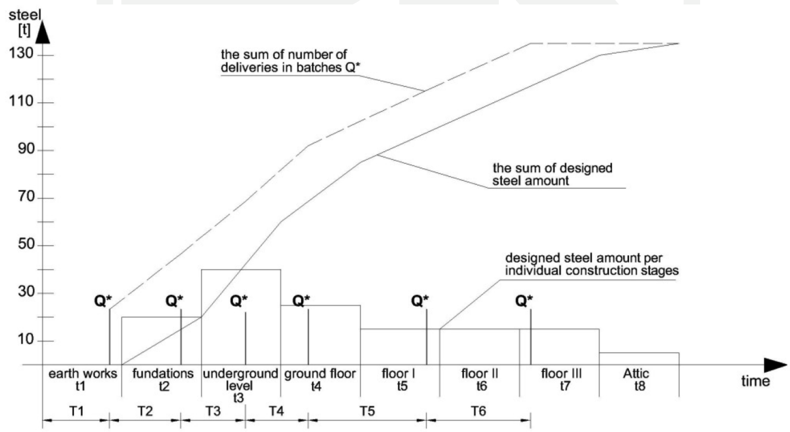

Fig. 2. Diagram showing steel demand for a building of improved conventional structure with trajectories of calculated material deliveries, Ti – intervals between deliveries, ti – reinforcement making durations at individual construction stages (Own study)

steel will be delivered by only one supplier (SPP) selected from among many others, e.g. on the basis of computations carried out using a transportation algorithm.

The formula defining optimal delivery volume at lowest possible logistic costs Q^* (*EOQ – Economic Order Quantity*) [8] is used to determine control variables for supply logistics management. Using this formula requires taking the following assumptions into account: a single product is ordered (one product type), the demand size (consumption, demand) is constant and known, orders are completed in a stable way (that is delivery completion time is constant), products are ordered and delivered in specific batches, delivery sizes can be characterised as optimal from a cost minimisation point of view and the cost structure is as follows: constant commodity unit cost, stock keeping cost linearly depends on an average stock level, the cost of making orders is constant in the case of each ordered batch, independently of its size.

Knowing the total steel consumption, it is possible to estimate Q^*, assuming certain level of costs involved in stock keeping and order handling according to the following formula:

$$Q^* = \sqrt{\frac{2 \cdot D \cdot k_s}{p \cdot c}}\,,\ n = \frac{D}{Q^*} \tag{1}$$

where:

- Q^* – the optimal delivery size [commodity unit],
- n – required number of deliveries to the construction site [pcs.],
- D – the total demand volume: 135 [t],
- k_s – unit order handling costs 600 [PLN/order],
- p – annual, percent rate of stock keeping costs [%/year] (stock keeping for one year) 15[%],
- c – unit cost of gathered stock 2000 [PLN/t].

According to the formula above, the optimal delivery size is Q^* = 23,24 [t]. Maximum load size in a standard mean of road transport (set consisting of truck and semitrailer) is 24 tons. The required number of deliveries (rounded to Q^* = 23 [t]) n = 5.81 [pcs.] is 6 (taking assembly bars into account). Due to the higher demand for steel during building raw state construction than will be used in successive storeys, it is planned to depart from deliveries at identical time intervals and reduce delivery cycle at initial period of construction works. Figure 2 shows distribution of deliveries to ensure designed steel volume and safe reserve.

Total logistic costs for supplying construction site with reinforcing steel in the discussed example can be estimated as follows [8]:

$$K_l = K_S + K_O + K_m = k_S \cdot n + c \cdot D + p \cdot c \cdot \frac{Q^*}{2} \tag{2}$$

where:

- K_S – order handling costs (purchase, including transportation),
- K_o – costs of freezing circulating means (capital),
- K_m – stock keeping costs (taking into account Q^* – optimal delivery batch, also called economic); other symbols as in formulas (1).

Minimum logistic costs planned according to the above calculations and assumptions have reached PLN 277,086 net.

4. Conclusions

Undoubtedly, the best steel delivery method from a theoretical point of view is model III – involving the supply of straight steel and prefabricated steel. It requires knowledge of sophisticated optimisation methods. Although owing to the computerisation it is possible to include the dynamics of market conditions and construction site specifics. There is some "inertia" in the implementation of results, caused for instance by former commitments between suppliers and consumers, it is not always possible to use it in practice. If steel demand per investment project allows for the selection of two suppliers in parallel, it is an advantageous negotiation argument for settling the price and ensuring continuity of deliveries to the construction site – in particular during a peak of orders for building materials during the year, which falls at the end of summer and the beginning of autumn.

Due to the nature and practice (supply logistics) of work on construction sites, the most suitable for use are: the graphical method for determining stock volume, the analytical-graphical method for determining stock volume, the buffer stock model and simulation models for determining stock volume with two and three unknowns. The graphical-analytical method is used most frequently by contractors, primarily because it is easy and clear. It gives results, which may be read directly from diagrams. These results allow for prompt analysis, owing to which we may quickly determine selected variables and modify the stock control model (in spite of the fact that obtained results do not satisfy all optimisation criteria). Moreover, data for calculations concerning the analysis are generated by professional applications for construction work scheduling, universally used in investment project implementation management. This gives us an opportunity to monitor logistic costs systematically during the construction, allows also for the planning and quick adjustment of objectives to dynamically changing progress in construction works.

References

[1] Downarowicz O., Krause J., Sikorski M., Stachowski W., *Zastosowanie metody AHP do oceny i sterowania poziomem bezpieczeństwa złożonego obiektu technicznego*, Politechnika Gdańska, ZEiEST, Poland, 2000, 7-42.
[2] Jaworski K., *Metodologia projektowania realizacji budowy*, PWN, Warszawa 2010.
[3] Krawczyk S., *Metody ilościowe w logistyce*, C.H.Beck, Warszawa 2001.
[4] Krzemiński M., *Metody podejmowania decyzji. Modele decyzyjne zapasu materiałów budowlanych*, (wektor.il.pw.edu.pl/~mkrz/Dydaktyka /MPD/MPD_ 4.pptx).
[5] Krzemiński M., Książek M., *Dobór modelu sterowania zapasami przy metodzie wielokryterialnej*, wektor.il.pw.edu.pl/~mkrz/Publikacje/.../Zakopane_ PLUKLT_2011.pdf.
[6] Michlowicz E., *Logistyka a teoria systemów*, AGH, Automatyka, Vol. 2 (13), 2009.
[7] Saaty T.L., *Decision making – the analityc hierarchy and network processes (AHP/ANP)*, Journal of Systems Science and Systems Engineering, March 2004,
[8] Sobotka A., *Logistyka przedsiębiorstw i przedsięwzięć budowlanych*, AGH, Cracow 2010.
[9] Szymański P., *Podstawy teoretyczne zarządzania majątkiem obrotowym* (http://zbc.uz.zgora.pl/Content/8527/index0.htm).
[10] Winnicki K., Jurek A., Landowski M., *Zastosowanie metody analizy hierarchicznej problemu* (p-e.up.krakow.pl/article/viewFile/682/554).