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Improvement of the grain cargo handling technology on the basis of resource-saving

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Abstract. The article considers the state of grain cargo transportation and related technical and technological problems. As a solution, the possibility of using multiple grain shipping containers and the introduction of a new modern grain cargo handling technology at the station based on inventory management and proper selection of vehicles was considered. The considered measures will contribute to simplifying, improving and reducing the number of cargo operations performed during grain handling, making their implementation more practical and energy-efficient.

1. Introduction

Grain cargo transportation takes a significant volume in the range of cargoes carried by transport and is one of the strategic products offered by the Ukrainian economy today. Grain has a significant impact on the development of the agricultural sector and is the main export product of the country. Grain cargo is mainly exported through seaports, while grain is delivered to ports mainly by rail (61%), road (36%) and river transport (3%). Therefore, the purpose of the article is to study the methods of loading grain cargo into a vehicle and organize optimal conditions to obtain the most effective quality indicators.

2. General part

The volume of grain cargo transportation is constantly growing [1]. The paper analyzes statistical data on the volume of grain and milling products transportation from 2009 to 2020 (Figure 1) [2]. The analysis shows that the volume of transportation has still been growing until now. Therefore, the transportation technology always has some shortcomings and, accordingly, the task arises to develop new resource-saving technologies.

The main problems in the grain transportation are: seasonal shortage of grain cars [3] and imperfect technology of grain loading complexes when such goods are transported in containers. The issue of seasonality of this cargo is considered in the model of cargo rolling stock management, which takes into account the parameter of uneven transportation [1].

The use of containers for loading grain has very good prospects, especially in the organization of export transportation, as labor-intensive and time-consuming cargo transshipment in ports are thus avoided [4]. Also, fewer grain cars which are not always available are required and more platforms are

used to transport containers, that are much cheaper than grain trucks and more versatile at any season. In addition, the likelihood of using containers increases that usually return empty after unloading in areas where grain cargo may be loaded.
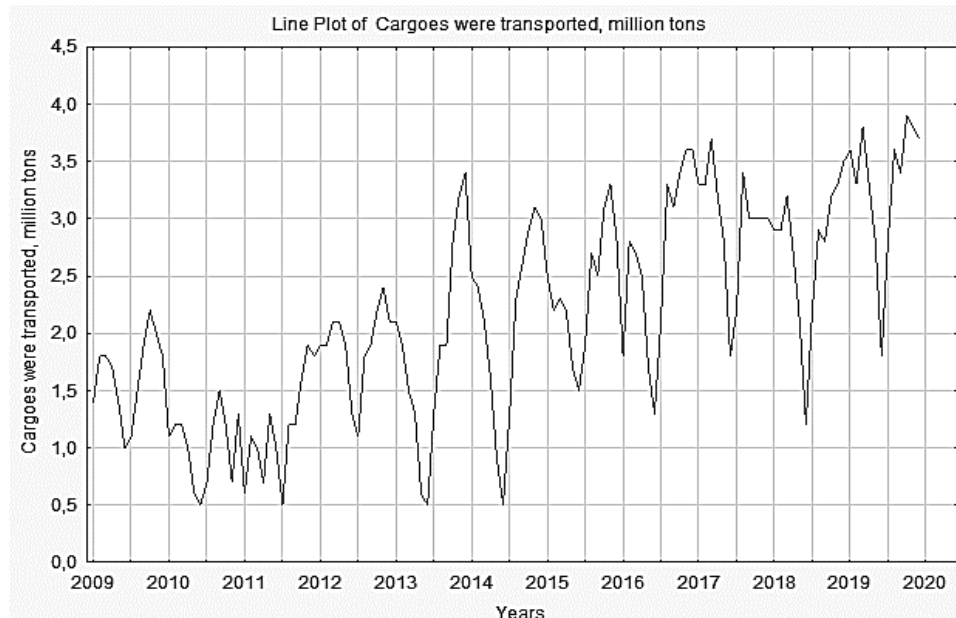

Figure 1. Transportation volumes of grain and milling products from 2009 to 2020.

One of the most important components in the entire cargo delivery chain is the organization of container loading at the points of departure. The loading technology for grain transportation containers can have various forms. Containers can be loaded directly on the site of the cargo owner and delivered to the railway station by vehicles designed specifically for container transportation, or grain cargo can be delivered by the owner directly to the grain warehouse of the station, where containers will be loaded and then placed on railway platforms. In [5, 6], the optimal placement of infrastructure facilities for primary grain handling is considered, while the feasibility of using various types of transport and forming an effective chain of grain transportation is discussed in [7, 8].

Therefore, the task is to develop a resource-saving technology for loading grain cargo, which will take into account as many factors as possible that influence the total cost of transportation, such as the number of loading and unloading machines (LUM), the number of deliveries to the warehouse complex and its operating time a day [9, 10].

To formalize the extreme task of improving the grain handling technology, a model of the functioning of the cargo front line (grain warehouse) has been developed.

To build a model, operating cost during performing work was selected as the optimization criterion, as it is one of the most important resource-saving components (table 1). The controlled parameter of the system is the handling capacity of the cargo front line Q_p, determined by the number of LUM M, deliveries of cars to the cargo front line Y, and the operating time during the day T. The problem of choosing a rational version of the operating technology for grain cargo handling is formulated as follows: for the specified characteristics of the input flow of requirements and the type of service system, parameters should be determined that correspond to the minimum value of the optimization criterion R_i.

Additional complication is the fact that there may be more than one option of the warehouse operation, depending on the capacity of the handled containers per day, the handling capacity of LUM per day, and the warehouse capacity. Therefore, the following conditions are taken into account when the optimal operating technology is determined:

- the capacity of containers processed per day is less than the handling capacity of LUM per day, the warehouse capacity is sufficient for storing cargo, i.e.

$$\sum_{i=1}^{f} N_{ki} Q_{H}^{\kappa o_{H}m} \leq \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} \leq Q_{sk}^{o},$$ cars are delivered to the warehouse by routes.

Table 1. Operating costs of grain handling at points of departure

Total cost	Indicator	Cost incurred during grain cargo handling	Indicator
Cost related to performing technological operations on the i-th cargo front line, UAH	R_i^{mexh}	Cost related to the delivery, arrangement, collection and pick-up of cars from the i-th freight front line, UAH	$W_i^{ман}$
		Cost related to the downtime of cars under cargo operations on the I-th cargo front line, UAH	$W_i^{н(в)}$
		Cost related to idle time of cars, because the i-th freight front line is in operation, UAH	$W_i^{вф}$
Cost related to cars waiting for service on the I-th freight front line and accumulation, UAH	$R_{oчi}^{ваг}$	Cost related to cars waiting for performing cargo operations when they arrive at the station during periods when the cargo front line is not in operation; UAH	$W_i^{во}$
		Cost related to cars waiting for maintenance, UAH	$W_i^{обсл}$
Maintenance cost of technical equipment of the I-th cargo front line, UAH	R_{ymi}^{mex}	Depreciation cost of LUM on the I-th cargo front line, taking into account the coefficient of efficiency of capital investments, UAH	W_i^{HPM}
		Labour cost of employees who operate LUM on the I-th cargo front line, UAH	W_i^{np}
		Maintenance cost of the I-th cargo front line and the labor cost of employees who operate it, UAH	$W_i^{вф}$
Cost associated with idle time of technical equipment on the I-th cargo front line, UAH	$R_{oчi}^{mex}$	Cost associated with idle time of motor vehicles when loading or unloading cars on the I-th freight front line, UAH	$W_{ai}^{н(в)}$
		Cost associated with idle time of vehicles because LUM is in operation, UAH	W_{ai}^{HPM}
		Cost associated with LUM waiting for performing cargo operations, due to the random coming of cars to the I-th cargo front line, UAH	$W_{HPMi}^{н(в)}$
Cost associated with the delay in processing transportation documents for cargo arriving or departing from the i-th cargo front line, and cargo en route, UAH	$R_i^{затр}$	Cost associated with the delay in processing transportation documents for cargo arriving or departing from the I-th cargo front line, UAH	$W_i^{док}$
		Cost associated with the delay of cargo, UAH	$W_i^{вант}$

Combined probability of a simultaneous event

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} \le Q_{sk}^{o}) =$$

$$= p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} \le Q_{sk}^{o} / \sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i), \qquad (1)$$

where $p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i)$ is the probability that the capacity of containers handled per day is less than the handling capacity of LUM per day;

$p(m_i P_{cmi} \le Q_{sk}^{o} / \sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i)$ is the conditional probability of the event in which the amount of cargo in a single serve is less than the storage capacity provided that the capacity of containers handled per day is not more than handling capacity for LUM per day, i.e. $\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i$;

N_{ki} is number of containers handled per day, cont/day;

$Q_{H_i}^{\kappa o \mu m}$ is container load capacity, kg;

P_{mi} is LUM productivity, t/h;

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} \le Q_{sk}^{o}) \cdot \varphi(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} \le Q_{sk}^{o}), \quad (2)$$

where $p(m_i P_{cmi} \le Q_{sk}^{o})$ is the probability of the volume of cargo in the delivery not exceeding the warehouse capacity;

$\varphi(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} \le Q_{sk}^{o})$ is a function that expresses the relationship between the probabilities $p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i)$ and $p(m_i P_{cmi} \le Q_{sk}^{o})$;

• the capacity of containers handled per day is less than the handling capacity of LUM per day, the warehouse capacity is insufficient for storing $\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} \le Q_{sk}^{o}$

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} \le Q_{sk}^{o}) =$$

$$= p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} \le Q_{sk}^{o} / \sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i), \qquad (3)$$

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} \le Q_{sk}^{o}) \cdot \varphi(\sum_{i=1}^{f} N_{ki} Q_{H_i}^{\kappa o \mu m} \le \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} > Q_{sk}^{o}); \quad (4)$$

- the capacity of containers handled per day is more than the handling capacity of LUM per day, the warehouse capacity is sufficient for storing cargo

$$\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} > Q_{sk}^{0}$$

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} \le Q_{sk}^{o}) =$$

$$= p(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} \le Q_{sk}^{o} / \sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i),$$ (5)

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} \le Q_{sk}^{o}) \cdot \varphi(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} \le Q_{sk}^{o});$$ (6)

- the capacity of containers handled per day is greater than the handling capacity of LUM per day, the warehouse capacity is insufficient for storing cargo

$$\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} \le Q_{sk}^{o}$$

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} > Q_{sk}^{o}) =$$

$$= p(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} > Q_{sk}^{o} / \sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i),$$ (7)

$$p_1 = p(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i) \cdot p(m_i P_{cmi} > Q_{sk}^{o}) \cdot \varphi(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} > Q_{sk}^{o}).$$ (8)

Rate setting condition: $\sum_{i=1}^{4} p_i = 1$.

Operation of the stochastic nature m_{and} i Q_{sk}^{o} are practically independent of each other, functions

$$\varphi(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} \le \sum_{i=1}^{f} M_i P_{mi} T_i, m_i P_{cmi} \le Q_{sk}^{o}), \qquad \varphi(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} \le \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} > Q_{sk}^{o}),$$

$$\varphi(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} \le Q_{sk}^{o}), \quad \varphi(\sum_{i=1}^{f} N_{ki} Q \textit{н}_i^{\textit{конт}} > \sum_{i=1}^{f} M_i P_{mi} T_i), m_i P_{cmi} > Q_{sk}^{o}) \quad \text{are}$$

assumed to be equal to one.

The continuity and reliability of the handling process depends on the level, rational use of the available equipment and the adopted technology. The conditions for the smooth operation of subsystems are determined by the load level of the interacting channels, which are calculated using load intensities. When cargo is handled:

$$\frac{24}{Y_i} \ge M[t_{onp}] + M[t_{np}] + M[t_{oн(в)}] + m_i k_{sdv} M[t_{н(в)}] + M[t_{onep}] + m_i M[t_{nep}] + M[t_{ocy}] + M[t_{cy}],$$ (9)

$$M_i P_m \geq \frac{m_i P_{st} + N_a P_a}{M[t_{н(в)}] + M[t_a]},$$ (10)

where Y_i is the number of deliveries to the warehouse per day;

$M[t_{onp}], M[t_{он(в)}], M[t_{oper}], M[t_{ocy}]$ are, respectively, the mathematical expectation of the waiting time for the performance of technological operations: spotting-arrangement, cargo handling, rearrangeent, collection-picking up;

m_i is the number of cars delivered to the cargo front line, cars;

k_{sdv} is coefficient of double operations;

$M[t_{np}], M[t_{н(в)}], M[t_{nep}], M[t_{cy}]$ is, respectively, the mathematical expectation of the time of performance of technological operations: spotting-arrangement, cargo handling, rearrangeent, collection-picking up;

M_i is the number of LUM on the I-m cargo front line, pcs;

P_m is productivity of LUM operating on the I-m cargo front line, t/h;

P_{st} is static load of the car, t/car;

N_a is number of vehicles handled on the I-th cargo front, pcs;

P_a is vehicle performance, t/h;

$M[t_a]$ is mathematical expectation of performing cargo operations with the vehicle.

Condition (10) indicates that the performance of LUM should match the rate of delivery of cars and vehicles to the cargo front line.

If the conditions for the smooth operation of subsystems is complied with, the efficiency of the station is increased because of the reduced negative impact of cause-and-effect relationships and rational use and loading of handling devices.

The minimum values M_i^{min}, Y_i^{min} are determined by the requirement to perform a given workload, and maximum values are determined by the availability of technical means.

$$M_i^{min} = \frac{k_i Q_i}{P_i T_i},$$ (11)

$$Y_i^{min} = \frac{m_i l_{ваг}}{l_{вф}},$$ (12)

where k_i is a coefficient that takes into account additional cargo handling operations;

Q_i is volume of cargo arrival or departure, t;

P_i is operational capacity of the LUM, t/h;

T_i is time of operation of the cargo front during the day, h; respectively, the number of LUM, deliveries to the I-th cargo front line and cars arriving at the I-th cargo front line per day, pcs;

$l_{ваг}, l_{вф}$ is respectively the length of the car and the I-th cargo front line, m.

When more than one freight front lines are handled with a single shunting locomotive, the operation parameters must be estimated as a single complex for all front lines at the same time, because the optimization criterion takes into account the costs associated with cars waiting for delivery and depends on the number of deliveries to all front lines.

The objective function of the model has the form

$$R = \sum_{i=1}^{f} R_i(M_i, Y_i, T_i) \rightarrow \min, \tag{13}$$

under the limitations
$$
\begin{cases}
\dfrac{k_i Q_i}{P_i T_i} \leq M_i \leq M_i^{\max}; \\[2ex]
\dfrac{m_i l_{ваг}}{l_{вф}} \leq Y_{and} \leq Y_i^{\max}; \\[2ex]
T_i^{\min} \leq T_i \leq 24; \\[1ex]
m_i \geq 0;
\end{cases}
\tag{14}
$$

Since each component of the function is a complex functional, the article shows the model implicitly. The function will further be considered explicitly.

As an example, the optimal functioning parameters of the grain warehouse based on a specific railway station are estimated. The obtained results are shown in the Figure 2.
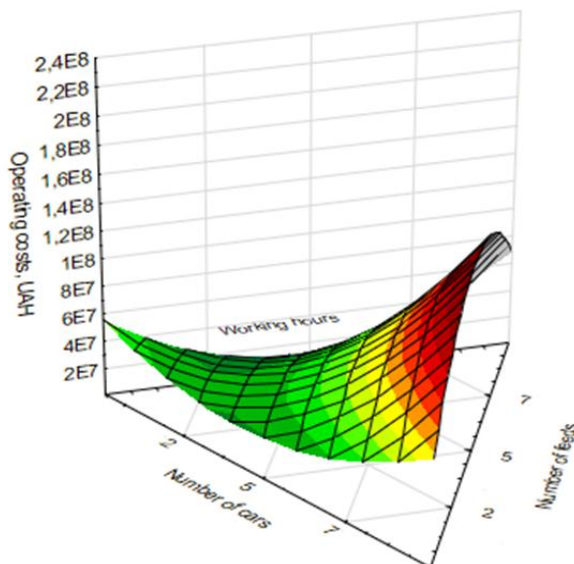

Figure 2. Result of estimation of optimal functioning parameters.

The results of estimations proved the presence of the extreme minimum, which allows us to determine the optimal number of loading and unloading machines, the number of deliveries and the operating time of the warehouse complex during the day, both in the stand-by and operational mode.

The proposed approaches can be used for the operational adjustment of the current situation, taking into account the predicted arrival of grain cargo for loading. It can be integrated into the decision support system in the corresponding automatic workstations of operational employees of the station: the station attendant, shunting dispatcher, acceptance/delivery inspector, process engineer, and others.

3. Conclusion

The volumes of grain cargo transportation and their seasonality have been analyzed. It is found that during peak loading periods there is an acute shortage of grain cars. Therefore, one of the ways to eliminate this shortage is to use grain shipping containers.

Possible variants of grain warehouse operation are determined, that take into account the ratio of the main parameters that affect the warehouse operation, including container capacity, warehouse capacity and handling capacity of LUM.

The operation technology of the departure point for grain cargo handling is formalized on the basis

of a stochastic programming model, which allows to minimize the total cost of loading and unloading operations and determine the optimal number of LUM, the number of deliveries and the working time of the warehouse complex during the day.

4. References

[1]   Butko T, Prodaschuk S, Bogomazova G, Prodaschuk M and Purii R 2017 Improvement of technology for management of freight rolling stock on railway transport *Eastern-European Journal of Enterprise Technologies* **3(87)**, 4-11

[2]   2020 Freight shipped by rail and type by freight State Statistics *Service of Ukraine* January July

[3]   Myamlin S V, Kozachenko D N and Vernigora R V 2013 Problems and Prospects of Transportation of Grain Freights by Rail in Ukraine *Railway Transport of Ukraine* **2(99)**, 32-34

[4]   Shuldiner Yu. V., Oliynyk Yu. O. Improvement of grain cargo transportation by rail *Car Fleet, Railway publishing house «Rolling stock»* **7**, 16-19

[5]   Seyed Mohammad Nourbakhsh, Yun Bai, Guilherme D N Maia, Yanfeng Ouyang and Luis Rodriguez 2016 Grain supply chain network design and logistics planning for reducing post-harvest loss *Biosystems Engineering* **151**, 105-115

[6]   Kozachenko D, Vernigora R and Rustamov R 2017 Creation of export-oriented network of grain elevators in Ukraine *Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport* **2 (68)**, 56-68

[7]   Michael F Hyland, Hani S Mahmassani, Lama Bou Mjahed 2016 Analytical models of rail transportation service in the grain supply chain: Deconstructing the operational and economic advantages of shuttle train service Transportation Research Part E: Logistics and Transportation Review **93**, 294-315

[8]   Elvis Ndembe and John Bitzan 2018 Grain freight elevator consolidation, transportation demand, and the growth of shuttle facilities *Research in Transportation EconomicsNovember* **71**, 54-60

[9]   Bagdonienė D and Mazūra S 2004 The optimisation of loading facilities at the terminal *Transport Vol XIX* **6**, 239-251

[10]   Pavlenko O and Volkova T 2020 Improvement of the grain delivery quality management by the ukrainian territory *Municipal economy of cities: Engineering science and architecture* **154**, 216-222