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rail-cars production; Kanban system; work-in-process; Markov chains

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THE MODEL OF WORK IN PROCESS INVENTORY MANAGEMENT OF RAIL CARS BUILDING COMPANY

Summary. The necessity of work-in-process management of rail-cars production by intelligent decision support software, which is based on JIT and Kanban principles, is identified. The scheme of one type cargo-flow movement between two workshops with control by electronic and traditional kanban-card is offered. For simulation of rail-cars production cargo flows Markov chain of M/M/1/1 type was applied. Simulation shows the dependence of the work-in-process on the in-flow and out-flow intensity. To determine the high level of the optimal work-in-process the stochastic inventory management model is applied.

УПРАВЛЕНИЕ ЗАПАСАМИ НЕЗАВЕРШЕННОГО ПРОИЗВОДСТВА ПРЕДПРИЯТИЯ ВАГОНОСТРОЕНИЯ

Аннотация. Обоснована необходимость управления запасами незавершенного производства в вагоностроении с помощью интеллектуальных программ поддержки принятия решений, основанных на принципах концепции JIT и системы Канбан. Разработана схема движения материального потока одного типа между двумя производственными подразделениями с управлением электронными и традиционными канбан-картами. Для моделирования перемещения грузов машиностроительного производства применена модель цепи Маркова типа M/M/1/1. Для определения оптимального размера запаса незавершенного производства применена вероятностная модель управления запасами.

1. INTRODUCTION

Material flow of rail-cars production includes: cargo-flow from internal supplier, which is managed by purchase department; work-in-process flow circulates between work-shops, warehouses, assembly line; finished product flow.

Movement and transformation of material flow into finished product is a chain of sequential process steps. Workshops, which supply work-in-process, are distant from assembly line. Industrial transport of engineering enterprise is classified on:

1. external workshop transport moves cargo between workshops and from maintenance warehouses to the workshops. External workshop transport included rail transport, trucks small motor vehicles;
2. internal workshop transport moves work-in-process during production cycle inside one workshop, provides transportation of assembly units from internal warehouses to the assembly line. Internal

workshop transport includes bridge cranes of high load capacity, assembly lines, supporting vehicles of small load capacity;

3. transport, which provides transportation from external suppliers. Often these functions are provided by external workshop transport.

Tank-car production cycle is series-parallel and consists of the following assembly units production: tank (9 days), carriage underframe (11 days), car track (9 days) and the whole assembly (2 days). The total cycle time is 13 days. Assembly units productions are of different length and start long time before final assembly.

The last production stage is assembly line, where tank cars are put together in the following sequence represented on fig. 1.

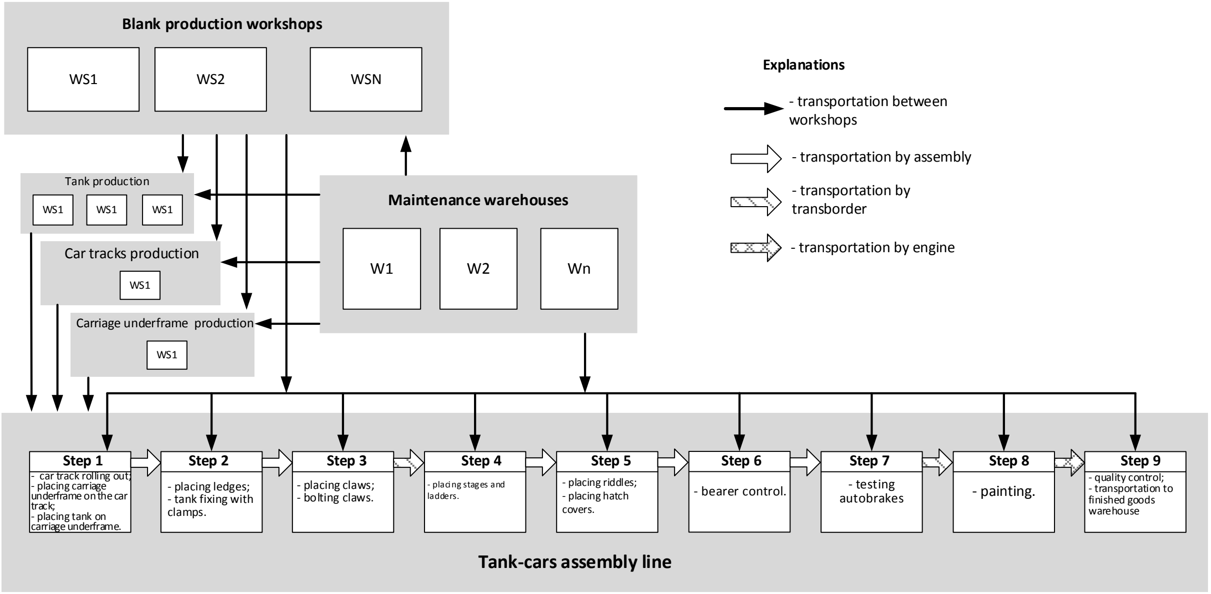

Fig. 1. The scheme of tank cars production material flow movement
Рис. 1. Схема движения материального потока производства вагонов-цистерн

Batches of tank-cars of different types are produced in sequence predetermined by production plan. Before the production of next tank-cars batch some time to set assembly line is needed.

Decomposition of tank-car assembly shows that depending on structure of internal cargo flow transported from workshops, the assembly line is divided into modules:

The first: for all types of tank-cars s production from one assembly one type cargo flow arrives, for example, standard car tracks and carriage for all tank-cars;

The second: one work-shop produces different types of one assembly unit for all tank-cars types;

The third: different workshops produce different types of one assembly unit.

The example of the last two modules is tanks production. There are workshops, which produces different types of tanks, and workshops which produce one type of tanks.

Production system functioning exists in conditions of external variable factors such as: offer updating depending on market demand; changing production volume; maintenance disfunction, including terms of work-in-process delivery; improving finish product modification, which leads to production reorganization and replenishment.

The internal variable factors, which causes production failure, are: failures and breakdowns of the main equipment; peripherals breakage; finished products and work-in-process defects; staff failure.

Ukrainian enterprises apply systems like classical ERP (Enterprise Resource Planning). ERP is a push type system of production and supply chains planning and management. Material flow movement through production cycle managed by centralized production management system.

The system provides consolidation of complicated production mechanism and all levels in production planning and management in the conditions of external variable factors. These levels are:

1. Strategic level is production capacity estimation, assortment and work content determination, work program and budget preparing.
2. Technical level is production planning on volume and terms, production program forming, associating to production startup and terms.
3. Operational level is equipment utilization schedule and daily and shift plans forming.

The disadvantage existing system is impossibility of real time analysis and instant decision making on material flow management in the conditions of internal variable factors. The result is execution of production plans with large amount of not added value costs or pure wastes.

It is possible to solve this problem by combining two inverse production logistics concepts: push concept like ERP system and pull concept like Kandan system.

ERP system will provide material flow planning and management on the highest levels: strategic and technical.

Kanban system will provide the real time material flow movement control during production on the operational level. Kanban system controls material flow with circulation of kanban-cards.

Kandan system developing means estimation of kanban-cards quantity for all types of moved parts. Cards quantity depends on customer demand and production intensity. The influence of internal and external factors makes production process variable, so the real time kanban-cards quantity calculating is necessary. For this purpose the intelligent decision support programs application is suggested.

The objective of this paper is developing the concept model of kanban-cards quantity estimation. The model could be applied in production processes, which exist in the large amount of variable factors conditions.

In the next part of the paper the inventory management model for module 1 of abovementioned classification will be described.

2. THE CONCEPT MODEL OF DECISION SUPPORT IN MANAGEMENT OF RAIL-CARS PRODUCTION WORK-IN-PROCESS

2.1. The objectives of inventory management

Inventory management problem of tank-cars production has two aspects:

1. Providing necessary inventory level for continuous production process.
   Cost minimization function is

$$z = \sum_{i}\sum_{m} C_{im}^{nocm} + \sum_{i}\sum_{m} C_{im}^{nep} Q_{im} + \sum_{i}\sum_{m} Z_{im} Q_{im} \to \min \tag{1}$$

$$Q_{im}^{\min} \le Q_{im} \le Q_{im}^{xp}$$

C_{im}^{nocm} – fixed cost on inventory i handling at stage m; C_{im}^{nep} – variable costs on inventory i handling at stage m; Z_{im} – financial losses due to tying up money in stocks; Q_{im} – level of inventory i at stage m; $Q_{im}^{\min}$ – level of safety stock i at the stage m; Q_{im}^{xp} – capacity of inventory i storage buffer at stage.

2. Supplying of assembly line with assembly units when required, sequence and assembly step. This aspect is of great importance due to great number of assembly units and different types of one assembly unit.

2.2. The scheme of material flow movement

In Kanban system assembly units move in standard batches - kanban-containers, which size is specified for all types of assembly units and depends on production conditions. For example, the batch of tanks is one tank, because tanks are moved from the workshop to the assembly line on tracks by one. Batch of car tracks contains four car tracks, because load capacity of truck is four.

One cargo type flow movement scheme between distant workshop and assembly line (Fig. 2). After production batches are stored at stage m output buffer of fixed capacity. There is a place at stage m+1 for storage one batch (kanban-container), because batches accumulate at stage m and moves to stage m+1 as needed.

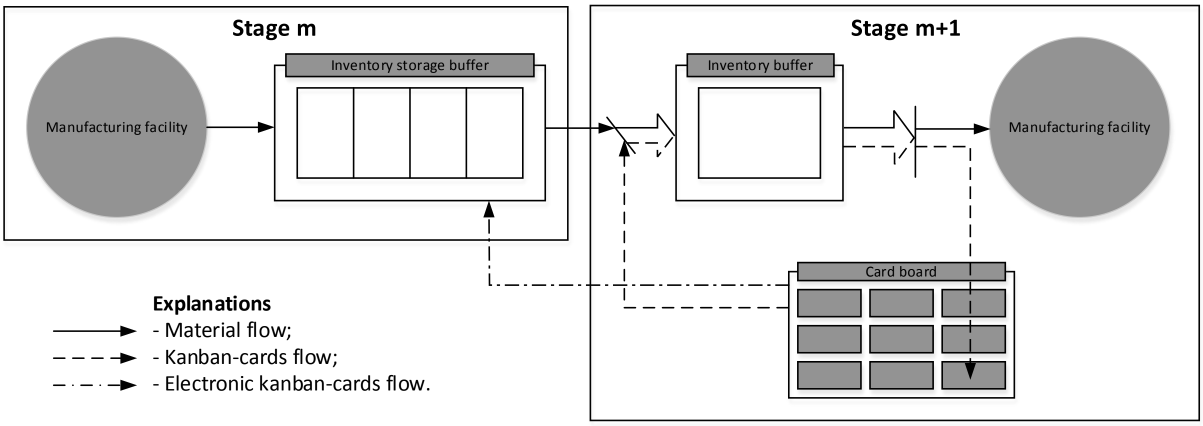

Fig. 2. One cargo type flow movement scheme between two production stages
Рис. 2. Схема перемещения одного тапа грузопотока между двумя производственными стадиями

There are three tools of material flow movement control: (1) set of kanban-cards, which circulates at stage m+1 and control production and demand at stage m+1; (2) electronic kanban-cards in form of electronic massages, which come from stage m+1 to stage m; (3) controlling board, located at stage m+1.

After taking kanban-container in production at stage m+1 attached to it kanban-card detached and moves to control board. From the control board card moves to input buffer and waits for kanban-container from stage m. At the same time electronic kanban-card goes to stage m and signalize the demand of kanban-container at stage m+1. If there is a kanban-container at stage m, it moves to stage m+1 without delay, kanban-card attached to it in inputs the buffer of stage m+1. Kanban-container waits production.

In case of kanban-container absence at stage m kanban-card waits for container. Capacity of storage buffer at stage m is limited, that is why stage m continues production as long as there is a storage place. Besides that, there should be a safety stock at stage m to maintain continuous production.

2.3. Mathematical description of the model

Analysis of demand statistics of tank-cars building enterprise shows, that demand flow (kanban-card flow from stage m+1 to stage m) has Poisson distribution with rate λ=16,25.

Inflow Poisson variability distribution is

$$P(k)=\frac{16,25^k}{k!}e^{-16,25}. \qquad (2)$$

Service time is time of intervals between production of kanban-containers, including time for movement between stages. Service time is exponentially distributed with parameter μ>0,

$$P\{\eta<t\}=1-e^{-\mu t}, t\geq 0. \qquad (3)$$

Service time is counted from the instant of electronic kanban-card delivered to stage m to the instant of kanban-container delivery to stage m+1.

The state of the system is described with parameters: quantity of active kanban-cards (cards, which are not attached to kanban-container), quantity of kanban-containers in the output buffer at stage m.

Let $N(t)$ define quantity of kanban-cards in the system at time t. Then $\{N(t), t \geq 0\}$ is birth and dead process with birth rate λ, dead rate μ, maximum population *K+2*, if $\rho = \lambda / \mu$ then

$$p(n) = \begin{cases} (1-\rho)\rho^n / (1-\rho^{K+2}), if\, \rho \neq 1 \\ 1/(K+2), if\, \rho = 1 \end{cases} \tag{4}$$

$p(n) = \lim\limits_{t \to \infty} P\left[N(t) = n\right], n = 0, ..., K+2$ steady-state probability distribution of stochastic process $\{N(t), t \geq 0\}$, where $p(n)$ – probability, that at any instant quantity of active kanban-cards in the system is n [1].

The described system is equivalent to Markov chain type M/M/1/1 with wait (Fig. 3).

The system is open-loop queuing system, because demand arrival is independent of service rate.

The average inventory level is average amount of kanban-containers at the output buffer on stage m: [1]

$$y = \sum_{n=0}^{K-1} (K-n) p(n). \tag{5}$$

Consideration of exponentially distributed service time is grounded on the following:

(1) Obtained characteristics are the highest level for all distribution laws, so the system parameters, calculated in that way, are maximum;

(2) We can always consider, that a lot amount of variable factors influences on service time. These factors make small impact to the final results and, as a consequence of the law of large numbers, service time should be close to the exponential distribution.

The lowest value of system characteristics are obtained when service time is determined.

The real systems parameters lie between determined and variable service time [8].

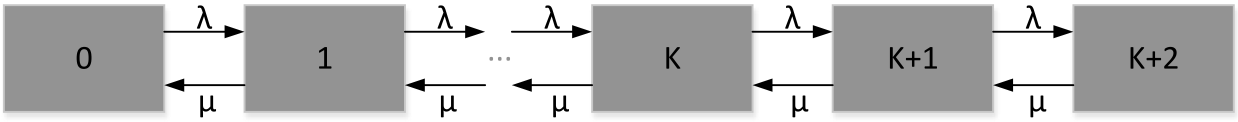

Fig. 3. State-transition rate diagram of system M/M/1/1
Рис. 3. Граф состояний системы M/M/1/1

Safety stocks depend on above-mentioned variable factors. In the conditions of rail-cars production the variable inventory management model applied to the safety stock is [5]:

$$Q = k\sqrt{m_{LT}\sigma_D^2 + (\sigma_{LT} m_D)^2}\ , \tag{6}$$

Q – safety stock; m_{LT} – expectation value of inventory replenishment; σ_D – standard deviation of inventory demand; σ_{LT} – standard deviation of inventory replenishment; m_D – expectation value of inventory demand; k - value of Laplace function for variability of fail-safe inventory replenishment P.

Fail-safe inventory replenishment is percentage of immediately served demand (P) [4]:

$$P = \frac{\sum_{i=1}^{p} SD_i}{\sum_{i=1}^{p} TD_i} \times 100\% , \tag{7}$$

SD_i – demand for inventory i served immediately; TD_i – the total demand for inventory i.

Distributions laws of demand flow and production flow are determined, so expectation value of Poisson distribution is λ, standard deviation is $\lambda^{1/2}$, for exponential distribution expectation value and standard deviation is μ^{-1}.

After putting distribution values in formula (6) we obtain:

$$Q = k\sqrt{\mu^{-1} \cdot \lambda^{1/2} + \mu^{-1} \cdot \lambda} = k\sqrt{\frac{1}{\mu}\left(\lambda^{1/2} + \lambda\right)} \tag{8}$$

2.4. The model application results

The model applied for the following parameters of the system: number of kanban-cards changes from 1 to 10, traffic intensity (ρ) changes from 0,05 to 1,55 with increment 0,1 (Tab. 1). The results of model application are represented on fig. 4.

Consider the practical model application for exact case: the demand rate is $\lambda = 9$ units/day, production intensity is $\mu = 10$ units/day, then traffic intensity is $\rho = 9/10 = 0,9$.

Table 1

The results of production process modeling

ρ	**Amount of kanban-cards in the system**									
	K=10	**K=9**	**K=8**	**K=7**	**K=6**	**K=5**	**K=4**	**K=3**	**K=2**	**K=1**
0,05	9,9473	8,9474	7,9474	6,9474	5,9474	4,9434	3,9474	2,9474	1,9475	0,9501
0,15	9,8235	8,8235	7,8235	6,8235	5,8235	4,8236	3,8237	2,8243	1,8284	0,8529
0,25	9,6667	8,6667	7,6667	6,6667	5,6669	4,6673	3,6689	2,6745	1,6941	0,7619
0,35	9,4616	8,4617	7,4619	6,4614	5,4638	4,4672	3,476	2,4977	1,5508	0,6791
0,45	9,1827	8,1837	7,1856	6,1896	5,1974	4,2127	3,2423	2,2987	1,4051	0,6051
0,55	8,7876	7,7943	6,8053	5,8232	4,8522	3,8986	2,9719	2,0861	1,2631	0,5398
0,65	8,2146	7,2447	6,2867	5,3446	4,4239	3,5315	2,6762	1,8698	1,129	0,4825
0,75	7,4035	6,4998	5,6166	4,7577	3,9271	3,1297	2,3713	1,6594	1,0057	0,4324
0,85	6,3526	5,5795	4,8279	4,0994	3,3958	2,7195	2,0733	1,4621	0,8944	0,3887
0,95	5,1693	4,5796	3,9998	3,4304	2,8723	2,3266	1,7954	1,2825	0,7952	0,3506
1,05	4,0294	3,6291	3,2224	2,8098	2,3919	1,9698	1,5455	1,1225	0,7076	0,3172
1,15	3,0686	2,8211	2,5565	2,2745	1,9751	1,6589	1,3269	0,9822	0,6308	0,2879
1,25	2,3293	2,1851	2,0212	1,8358	1,6276	1,3955	1,1394	0,8605	0,5637	0,2623
1,35	1,787	1,7056	1,6066	1,4826	1,3448	1,1766	0,9804	0,7557	0,5051	0,2396
1,45	1,3957	1,3501	1,2908	1,2147	1,1178	0,9964	0,8466	0,6657	0,4539	0,2197
1,55	1,1122	1,0865	1,0509	1,0023	0,9364	0,8488	0,7343	0,5885	0,4092	0,2019

For variability of fail-safe inventory $P = 0,98$ value of Laplace function is $k = 2,05$. Capacity of inventory storage buffer is $Q^{\max} = 4$ kanban-containers.

Safety stock level, calculated on formula 2 is: $Q = 2,05\sqrt{\frac{1}{10}(\sqrt{9}+9)} = 2,46$ kanban-containers.

For given traffic intensity the optimal number of kanban-cards is 5,6 or 7. The decision should be the following: for saving daily production amount of 9 units with traffic intensity of 0,9, inventory level 5 kanban-containers will exceed the capacity of inventory storage buffer.

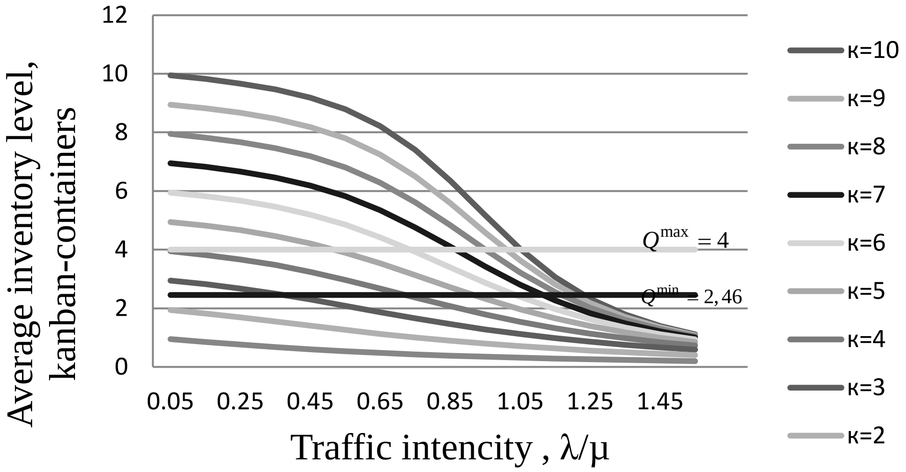

Fig. 4. Inventory level - traffic intensity diagram
Рис. 4. График зависимости запаса в системе от интенсивности движения

For saving inventory between $Q^{\max} = 4$ and $Q^{\min} = 2,46$ the traffic intensity should be decreased for $\rho = 1$ by increasing production intensity.

3. CONCLUSIONS

Based on analysis of tank-cars production material flow system the improvement of inventory management system is proposed by combining two inverse production logistics concepts: push concept like ERP system and pull concept like Kanban system.

Proposed intelligent decision support model allows determining the optimal production volume on criterion of optimal inventory level and decision support on production plans execution.

The future researches will be directed on: (1) developing inventory management model for the case, when one workshop produces and supplies different modification of one assembly unit to assembly line; (2) developing ways of integration subsystems into one production and management mechanism; (3) developing technical ways for practical application of developed models.

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