

Applicability and Methods of Lean Production in Railway Transportation Organization: A Case Study of Urumqi Railway Bureau in China¹⁾

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Abstract

The concept of lean production originated and was applied mainly to manufacture industries with tangible products. Even proven successful with such companies as Toyota, lean production has to be combined with the characteristics of railway transportation production in order to bring its function into full play. The paper analyzes theoretical foundations for applicability of lean production in railway transportation production organization, puts forward implementation methods such as transportation resource integration, station-zone organization, dispatch command optimization, railway performance evaluation index system, etc., and makes an exemplification study of lean production of Urumqi Railway Bureau in China, which testifies the applicability and efficiency of railway lean production.

Keywords : lean production, railway, transportation production, applicability, Urumqi railway bureau

1. Introduction

In 1990, Womack, Jones and Roos generalized an important concept of Lean Production (LP) from the analysis of Toyota Production System (TPS) practice for the first time [1]. LP, in essence, is a managerial way for enterprise production organization, adopts pull management through value chain reengineering, so as to effectively allocate scarce resources and optimize organization and reach the goal of cost reduction, revenue increase, customer value improvement, and enterprise core competence establishment. As a kind of modern management innovation, LP originated and was mainly applied to manufacture industries, and concerning literatures written by Monden, Ohno, Krafcik, Womack, Jones, Roos, Sakakibara, Hopp, Shah, Rachna [2], etc. summarized LP system from different perspectives as shown by Fig. 1.

With perfection and dissemination of LP theory, some scholars start to think over whether LP is suitable for service industries, for example, Par Ahlstrom [3] in Sweden and Dunning in U.S.A maintain that LP can be applied to service sectors. Urumqi Railway Bureau (URB) in China pioneered LP experiment in Hami railway sub-bureau in

year of 2002. From 2005 to 2007, URB began to implement LP systematically at railway bureau, station-zone and station-and-depot levels. Even though some achievements were obtained, except for several articles written by Rong Chao-he, Li Hong-chang [4], Song De-xi, Dean Wise, etc., we can hardly find any literature which further discusses theoretical foundations and methodology of LP in railways. Under the condition that there is a shortage of analysis on railway LP applicability and implementation methods, on 2006 Lanzhou Sino-Japan enterprise management symposium in China, some Japanese scholars even regarded LP practice of URB as a process control rather than the classical LP operation, and asked about the foundations and ways supporting LP practice.

Thereby, we aim to discuss the applicability and methods of LP in railways, and try to draw out conclusions and suggestions for railway management innovation with URB LP practice as an illustration.

2. Applicability of Lean Production in Railway Transportation Production

According to the theory of Herbert Kitschelt [5] in Duke

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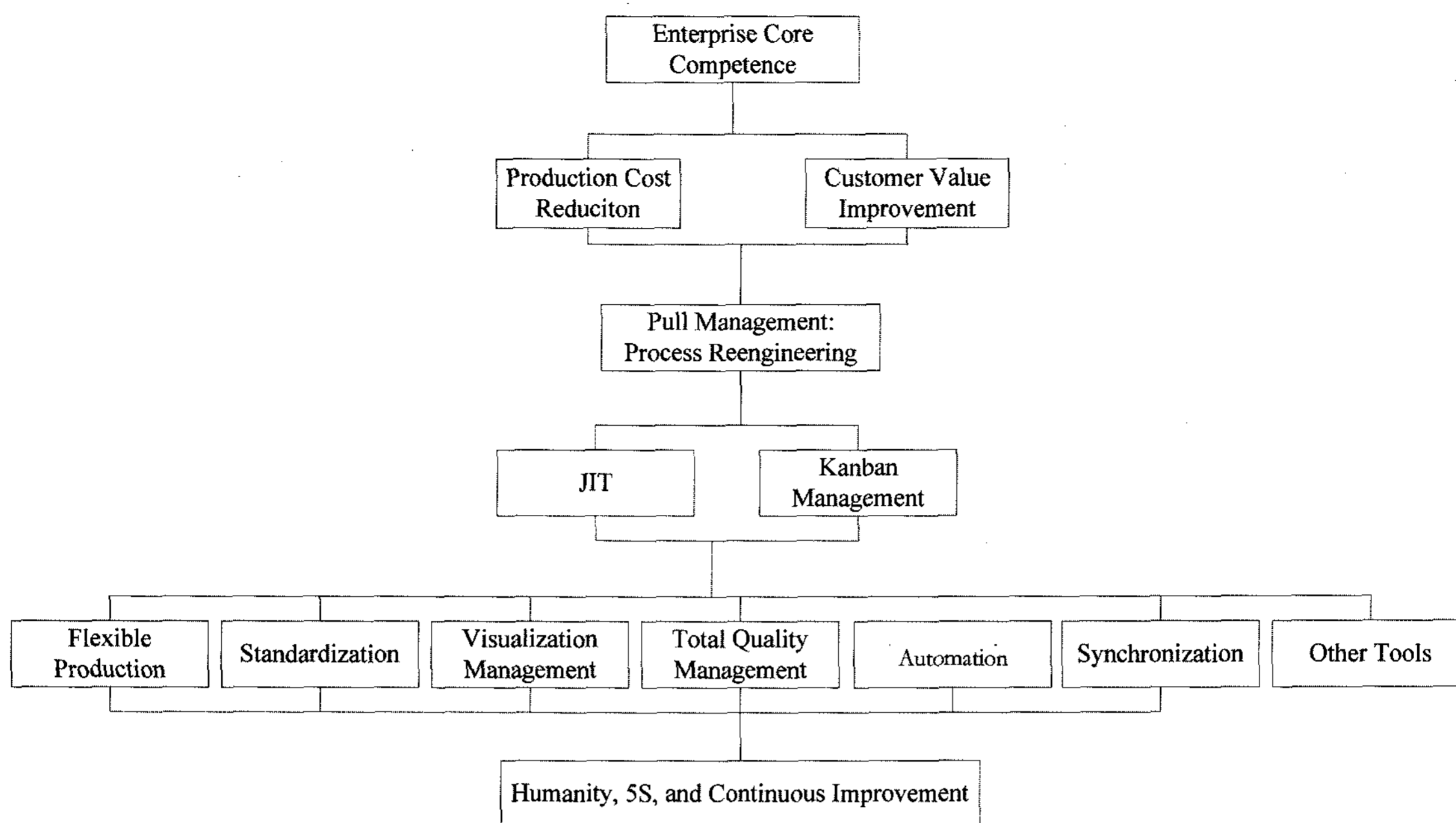


Fig. 1 LP System of Manufacture Enterprise

University, every industry has a set of core technical features, which, in turn, leads to variety of governance structure and management peculiarity. We argue that since industrial core technical features determine both managerial structure and relationship of production factors in the dimension of time and space, it's imperative to combine those features of railway transportation with LP so as to obtain prominent performance in cost saving and value creation.

2.1 General Lean Production Fundamental Ideas and Techniques

LP is a set of socio-technical system which provides such tools as JIT, Kanban, zero inventory, flexible production, teamwork, visualization, flat organization, etc., which are helpful for enterprise production, supplier coordination and customer service satisfaction. During production process, only necessary parts or semi-products are pro-

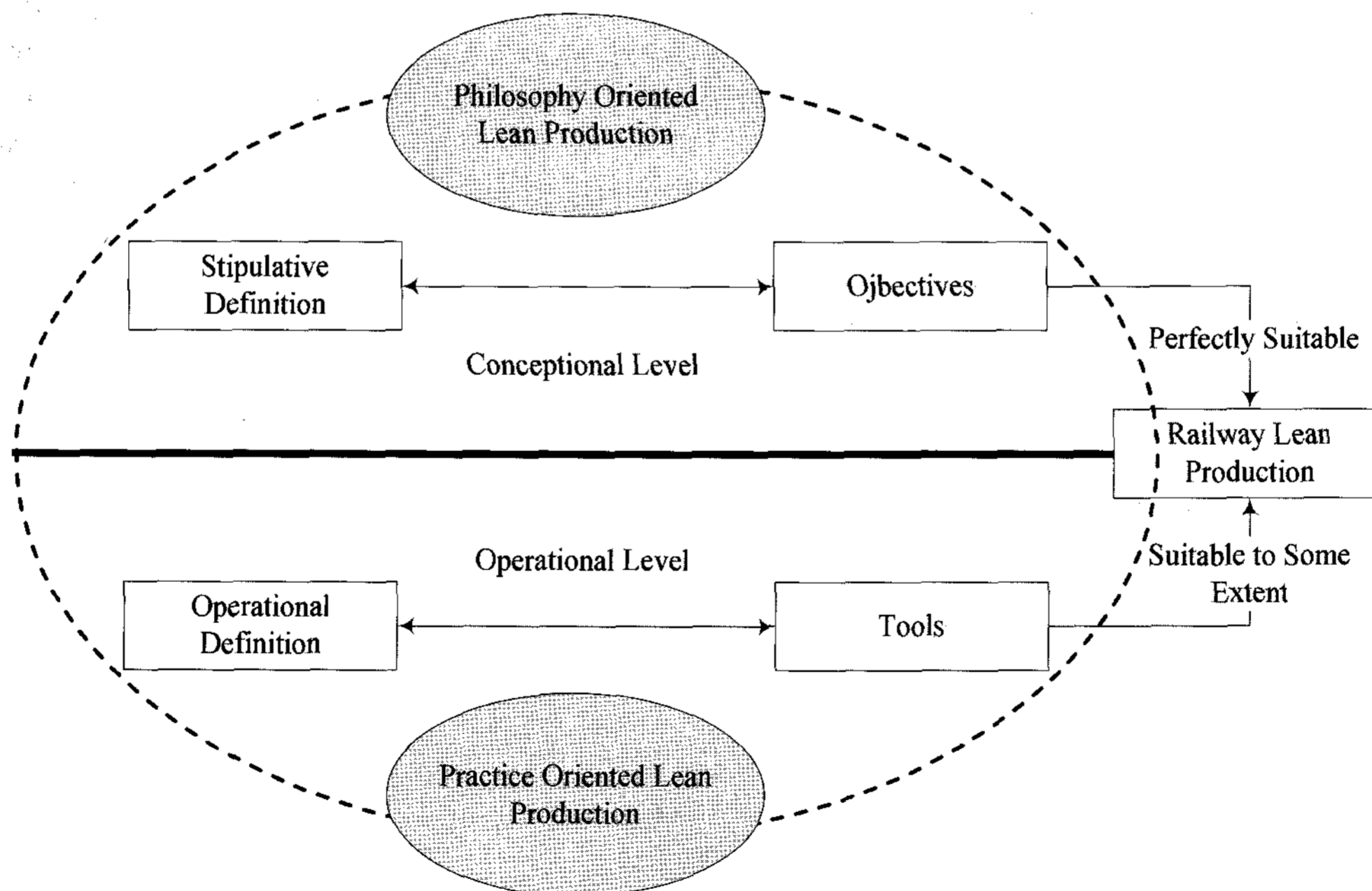


Fig. 2 Applicability of Lean Production in Railway Transportation Production

duced for the next working procedure, otherwise, production activities that cannot add value to the final product demanded are defined as wastes which include excessive production, redundant stock, unnecessary material transportation, needless movement, time waiting for the next production procedure, waste caused by assembly or design, product defect, etc.

By taking advantage of operational tools, LP pursues such objectives as follows: (1) Eliminate waste. All kinds of waste are eliminated through value stream simplification by finding, defining, and analyzing core business processes and supplementary ones. (2) Satisfy customer demand. Customer demand is the starting and final point of LP. Under the condition that market competition

becomes fiercer and fiercer, it requires that all production activities are carried out with market demand at the core. The better the quality of service, the greater the utility of customer, customer demand is the only criteria to evaluate LP activities. (3) Release initiatives of employees. It's important to design process-oriented organization, transfer management rights down to the people on spot, and encourage people at the grass-root level to work hard by giving them more control right, disposition right and benefit right. Besides, performance evaluation and assessment index system also plays an important role to clarify the responsibility and right of different departments inside enterprise. (4) Establish partnership with suppliers. Only under strong support of suppliers, can the objectives of LP

Table 1. Railway Transportation Resources and Relative Functions [8]

Resource Category	Sub-category	Concrete Resource Item	Basic Function	
Internal Resource	dispatch command system	passage capability of limitation interface between railway bureaus	restriction on train sets in-and-out railway bureaus	
		technical route or plan of dispatching command	traffic control of trains and multifarious resource of their time and space distribution	
	delivery capability guarantee system	trunk line of railway network		train passage
		station hinge	line	train, passage, concentration, marshalling
			freight facilities	cargo delivery acceptance, pick up, load and unload
			passenger facilities	ticket sell, on-and-off train
		locomotive		power to haul, marshalling, fetch and send wagon
		wagon	freight wagon	load freight
			passenger car	load passenger
	empty wagon		restriction on loading numbers of railway bureaus in shortage of wagons	
	equipment maintenance system	routine maintenance of line, locomotive, wagon, and etc.		provide basic condition for train running by facility and equipment maintenance
	supplementary system	communication facility		transfer information and order
		water and electricity facility		provide water and electricity
		other supplementary facility		guarantee smooth running of trains
	other resource system	human capital facility		labor working force
		finance capital		supply finance flow
information		exchange and communication among people		
organization management and marketing capability		management organization and institutions		
External Resource	enterprise specialized line		freight concentration, load-and-unload, storage	
	customer		facilitate organization of non-stop train	
	cooperation enterprise		shoulder outsourcing activities of railway transportation enterprise	
	superior government administrative department		policy supportive measures	
	local government		policy support and coordination	

such as storage reduction, capital cost downsizing and product quality improvement be realized. By establishing cooperation mechanism with suppliers, LP makes it possible to extend production process to the internal management procedures of suppliers. (5) Create sound culture of continuous improvement. The final objective of LP is to create a lean enterprise with continuous improvement culture and turn norms and rules into self-conscious behavior.

Generally speaking, from perspectives of basic philosophy, operation tools and main objectives [6] of LP, it's safe to say that LP can be universally applied to not only manufacturing industries, but also service ones, let alone railway transportation sector. See Fig. 2.

Seen from fig. 2, LP can be applied to railway transportation production at two levels. At the conception level, it's completely suitable for railway to adopt LP in order to reduce production cost, improve customer satisfaction and build up enterprise core competence through pull management. At the operational level, it's applicable, to some extent, for railway to adopt operational tools including but not limited to JIT, Kanban management, flexible production, etc.

2.2 Lean Production and Production Features of Railway Transportation

There is no doubt about whether the conception of LP can be applied to railway transportation production, however, questions still remain as to whether all LP tools can be simply transplanted to railway industry without any

modification. The paper maintains that railway transportation has special production characteristics different from those of manufacture enterprises, thus, LP has to be modified so as to be adapted to realistic railway operations. For example, railway transportation product is consumed while produced, and consumption and production are the two sides of the same coin. Thus, inventory management is useless in railway transportation production if consumption and production are of synchronization. Obviously, railway production characteristics have important restriction or acceleration impact on LP applicability. But, as a whole, even though some LP operational tools are of no use, most operational tools of LP can be coupled with railway transportation production characteristics, and can effectively coordinate varied transportation resources, save transportation production cost, improve transportation product quality, upgrade client value, and shape corporate core competence [7].

2.2.1 Analysis of Railway Transportation Production Characteristics

Transportation resource, which refers to the sum of dispatch command, locomotive, wagon, maintenance, electricity, personnel, infrastructure and management measures whose main purpose is to realize passenger and cargo spatial movement, forms the conditions and instruments for transportation activity. See Table 1.

In Table 1, railway transportation resources fall into two categories, that is, internal resource and external resource,

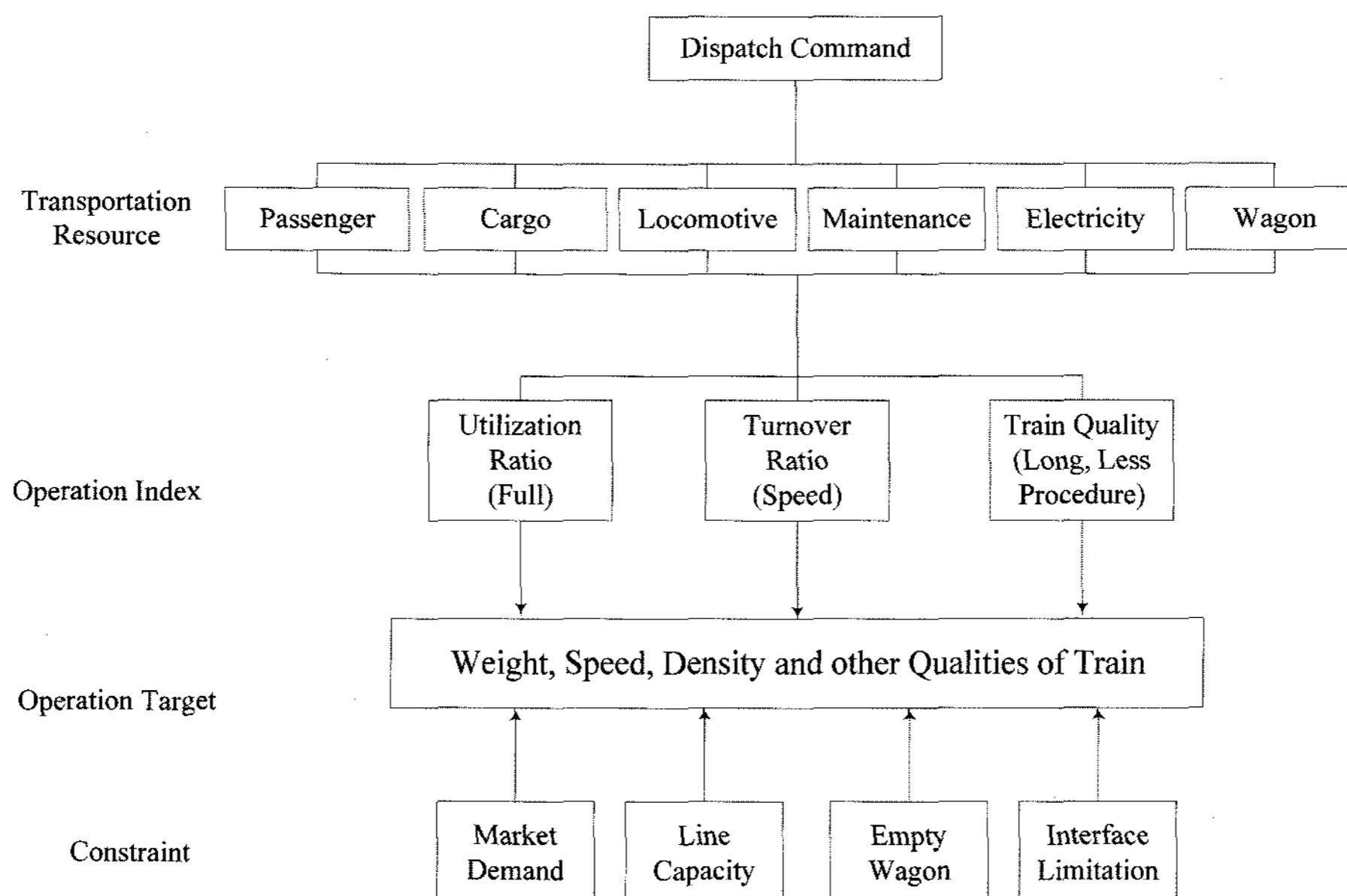


Fig. 3 Economic System of Railway Transportation Production

Note: cited from the book written by Rong Chao-he, Li Hong-chang, Lean Management of Railway Transportation Organization (Working Paper), 2008.

of which, internal resource including trunk line, dispatch command technique, locomotive, wagon, communication, etc. External resource consists of enterprise special line, customer, superior government administrative department and local government, etc. With run diagram and daily dispatch command at the core, railway operational system (see Fig. 3) targets at better realization of distance economy. In other word, through improvement of turnover ratio, wagon loading ratio and train organization quality, railway can reduce transportation cost dramatically as transportation distance increases.

According to the analysis of railway transportation economic system, we can summarize several characteristics of railway production as follows: (1) Railway transportation production provides market with intangible spatial movement service. What passenger and cargo shipper need is invisible railway movement from origination to destination. Time-effectiveness of railway transportation product is so high that payment willing of consumer would fluctuate a lot if transportation production plan was carried out on schedule or adjusted. (2) Railway transportation production uses multiple kinds of production factors, and produces multi-products with complicated work division and cooperation relationship. In order to supply railway transportation product with different time, space, direction, speed, safety, comfort dimensions, hierarchy and flatted organization structures and management system have to be built up to coordinate relationships inside and outside railway enterprise. (3) Railway transportation production is confronted with high level uncertainty, of which, railway transportation activity unfolds in an open environment, wind, sand, rain, snow and other climate uncertainty will interfere with railway production process; transportation demand fluctuates greatly in market economy, which will certainly interfere with railway production process; railway transportation has complicated technical cause-and-effect relationship, the probability of accident will interfere with railway production process; railway transportation activity is under strict government regulation, interest groups will lobby and seek rent, it's unavoidable that railway production process will be interfered with. (4) Railway transportation production is of profound network economy [9], which is the sum of scale economy and scope economy. The former refers to the phenomenon of decreasing average transportation cost with the increasing transportation volume on railway network, while the latter refers to the phenomenon of decreasing average transportation cost with multi-product production. As we know, railway transports coal, wood, mineral ore, corn, cement, and etc. in large bulk, and transportation equipments always serve multi-product production purpose, therefore,

network economy is better in railway than in other sectors.

2.2.2 Analysis of Lean Production Applicability in Railway Transportation Production

If coupled with railway transportation production technical characteristics, LP can be perfectly adapted to railway transportation production process, enhance railway transportation organization optimization, ameliorate transportation resource allocation efficiency, and shape core competence of railway transportation enterprise. The reasons are as follows:

(1) LP can effectively adapt to production process of railway transportation product and improve its punctuality. The output of railway transportation is intangible spatial movement, and consumption and production are the same production process. Thus, it's impossible for railway enterprise to produce in advance and sell in late days. Through run diagram and routine traffic control optimization, railway LP can organize non-stop trains, improve line passage density and average wagon load weight, reduce useless locomotive waiting, etc. Especially, when some accidents beyond expectation arise, LP can retrieve or adjust production chain rapidly so as to improve quality and quantity of railway transportation product.

(2) LP can effectively coordinate complicated work division and coordination activities. Railway transportation production inputs a set of production factors and outputs multi-products, therefore, it will involve multiple working units, broad management span, complicated activity chains. By means of LP operational methods such as modularity, JIT, standardization, institution, etc., responsibility and rights of different functions can be clarified, core business process and supplementary business process can be identified, and transportation resource and organization mode can be optimized.

(3) LP can effectively reduce or eliminate various kinds of uncertainty [10]. Railway transportation production cannot avoid such uncertainties as environmental uncertainty, market uncertainty, technical uncertainty, and man-made uncertainty. All of the possible uncertainties can lead to change of railway run diagram which is planned beforehand. By adopting Kanban management, teamwork organization, lean maintenance and technical operation, railway LP can, to the extreme extent, take most factors which can influence railway production into consideration, correspondingly, improve the level of just-in-time production, fix transportation tasks in advance, and respond to accidents rapidly. Thus, railway transportation production can be executed in a smooth and balanced way.

(4) LP can effectively realize network economy in transportation production. In transportation process, network

Table 2. Decomposition of Network Economy in Transportation Industries [11]

Scale Economy and Scope Economy		Density Economy and Size Economy	Specific Forms of Network Economy			Relationship	
Scale Economy	Density Economy	Track Density Economy	Single Product Density		Transportation volume increases while size keeps stable	Change together	
			Multi-product Density				
			Movable Equipment Capability Economy				
			Wagon, Ship or Plane Fleet Economy				
Station or Port Disposal Capability Economy							
Scope Economy	Size Economy	Line Extension	Distance		Size expands while density keeps Stable		
		More Service Points	Multi-product economy because of size expansion				

economy, which is the sum of scale economy and scope economy, transforms into density economy and size economy, see Table 2. Economy of density refers to decrease of cost with expansion of transportation volume while size keeps constant. Economy of size refers to decrease of cost with expansion of size or track miles while density keeps constant. Of which, track density economy refers to the phenomenon when average transportation cost reduces as transportation density on specific line increases, or the density index of ton-kilometer per kilometer goes up. Whereas single product density can lead to decrease of average transportation cost, multi-product density also contributes to cost savings for transportation production. Movable equipment capability economy means that average transportation cost reduces while load weight of transportation equipment mounts up. Fleet economy of wagon, ship or plane refers to the phenomenon that average transportation cost decreases when number of means of conveyance in one organization group grows up. Station or port disposal capability economy indicates that average transportation cost decreases as wagon, container or cargo and passenger throughput increases at specific station, airport, or port in transportation network. Distance economy is the phenomenon that transportation cost reduces as shipping distance prolongs.

Through resource pull, process pull and product pull, railway LP adjusts spatial layout of transportation resources, cut down useless production procedures, and improve both quality and quantity of transportation product. Whatever methods railway LP takes, performance of railway transportation enterprise manifests finally as the quantity and quality of passenger and cargo trains on railway lines. Railway transportation product is produced through passenger or cargo trains whose organization determines technical efficiency, management efficiency and transaction efficiency of railway transportation enterprise. Quantity index of train can be measured by number of trains passing certain line overnight, in short, train density,

while quality index of train can be computed by weight, speed, punctuality, and operation distance. By taking advantage of LP measures such as vehicle weight improvement, production process reengineering, assessment index constraint, etc., quantity and quality of train operation can be improved, at the same time, transportation cost can be cut down dramatically, and potential transportation production power can be released further.

3. Implementation Methods of Lean Production in Railway Transportation

Except for ordinary LP methods universally adopted such as pull management, JIT, Kanban management, flexible management visualization management, etc., it's necessary to develop special LP methods which take railway transportation production characteristics into consideration.

3.1 Method System of Railway Lean Production

Railway LP system, with pull management at the center, mainly consists of transportation resource integration, transportation process reengineering, dispatch command optimization, station-zone organization, railway incentive-and-constraint mechanism, etc., as shown by Fig. 4.

In Fig. 4, transportation resource forms the foundation for railway LP, transportation process is the carrier, dispatch command system plays a key role, and station-zone organization and incentive-and-constraint mechanism are security system which make railway LP practical in practice.

3.2 Several Methods to Implement Railway Lean Production

Taking railway specific production characteristics into consideration, the paper innovatively puts forward railway LP method system and concrete implementing ways such as non-stop train organization oriented process reengineering, dispatch command optimization with run diagram and

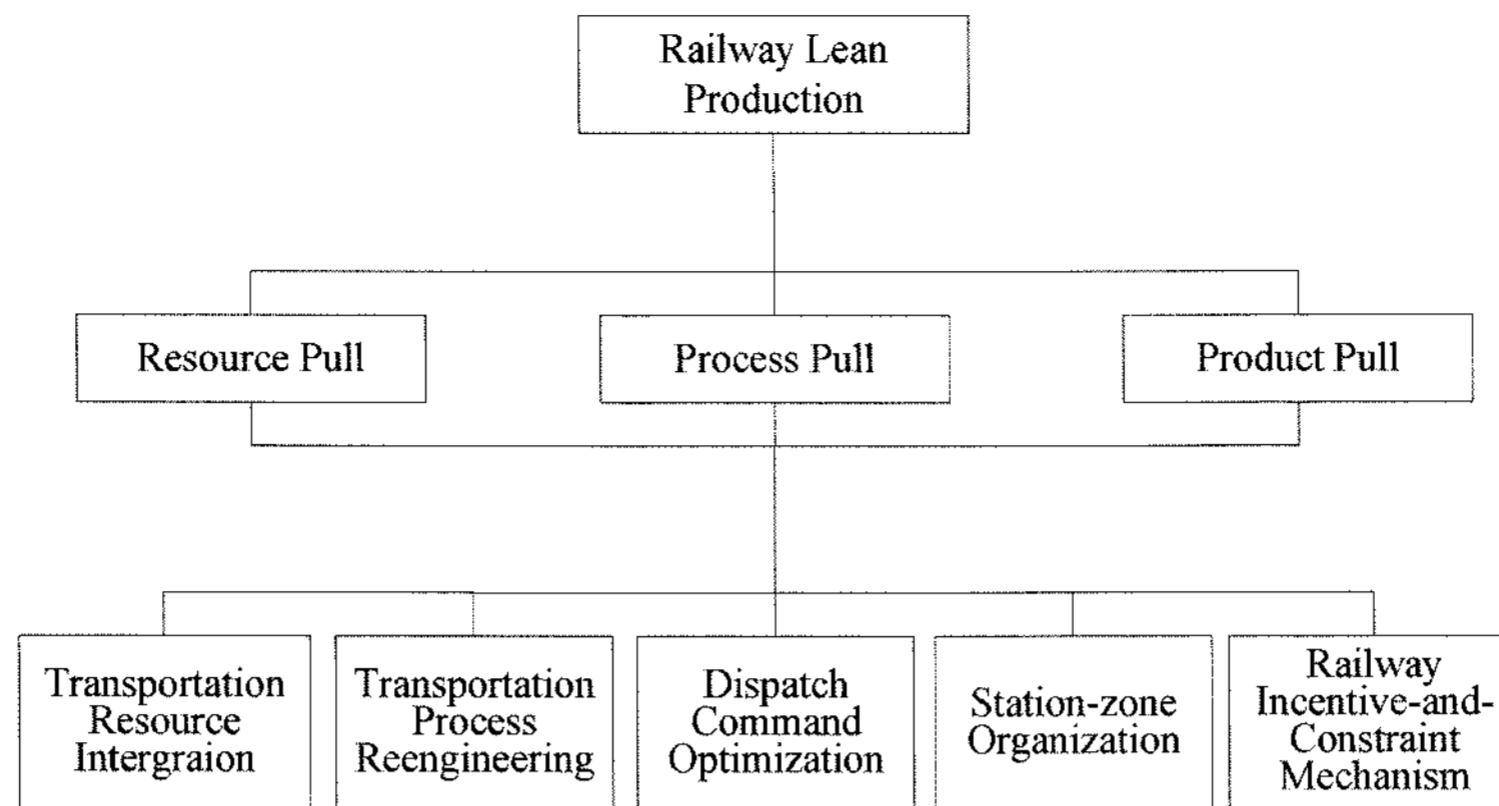


Fig. 4 Railway Lean Production Method System

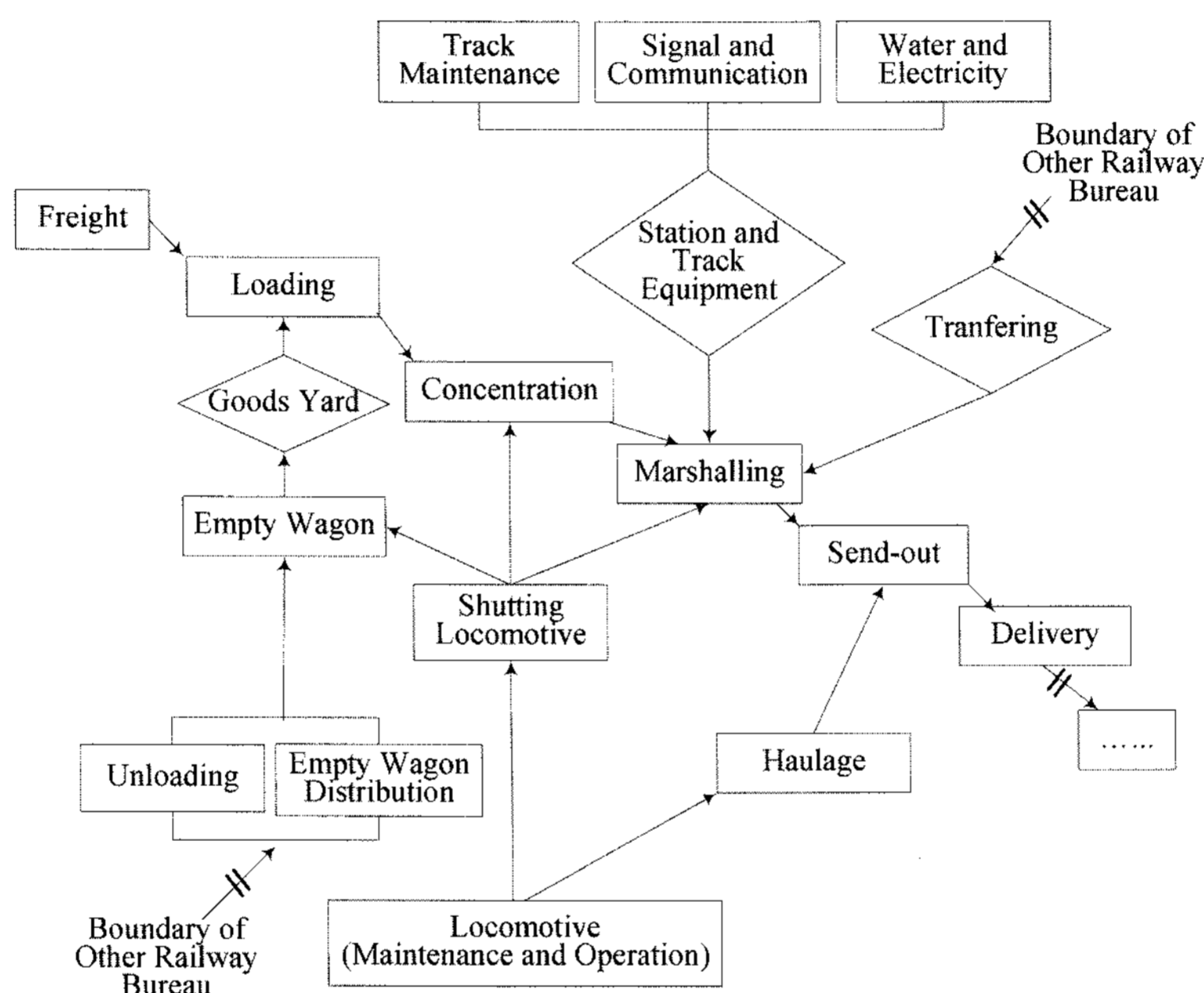


Fig. 5 Railway Freight Transportation Production Process

routine traffic control at the core, evaluation and assessment index system, etc.

3.2.1 Transportation Resource Integration Method

Transportation resource integration is a railway LP method which improves structural and operational relationship between different transportation resources such as line, station, marshalling yard, locomotive, wagon, signal, maintenance, water, electricity, supply of goods, etc., so as to increase allocation and operation efficiency of railway transportation resources. The effects of transportation resource integration can be analyzed through two aspects: (1) In the aspect of transportation resource spatial distribution, redundant quantity of operational organizations are integrated into large-scale ones in charge of enterprise spe-

cial line, marshalling yard, dispatch command unit, locomotive depot, wagon depot, maintenance base, etc., which serve larger territory compared with that before transportation resource integration. Because of unified allocation of transportation resources, distance economy is brought into play and railway production efficiency increases accordingly. For example, through Kuerle station resource integration in URB, the number of shutting locomotives was cut down from 4.5 to 3, and actual usage ratio increased from 60% to 90%. (2) In the aspect of resource operation activity relationship optimization, it's notable that phenomenon of repeated operation, scattered cargo loading-and-unloading, unmatched capability of point and line, etc., rarely happens after railway resource integration. For example, there are 601 enterprise special lines within the

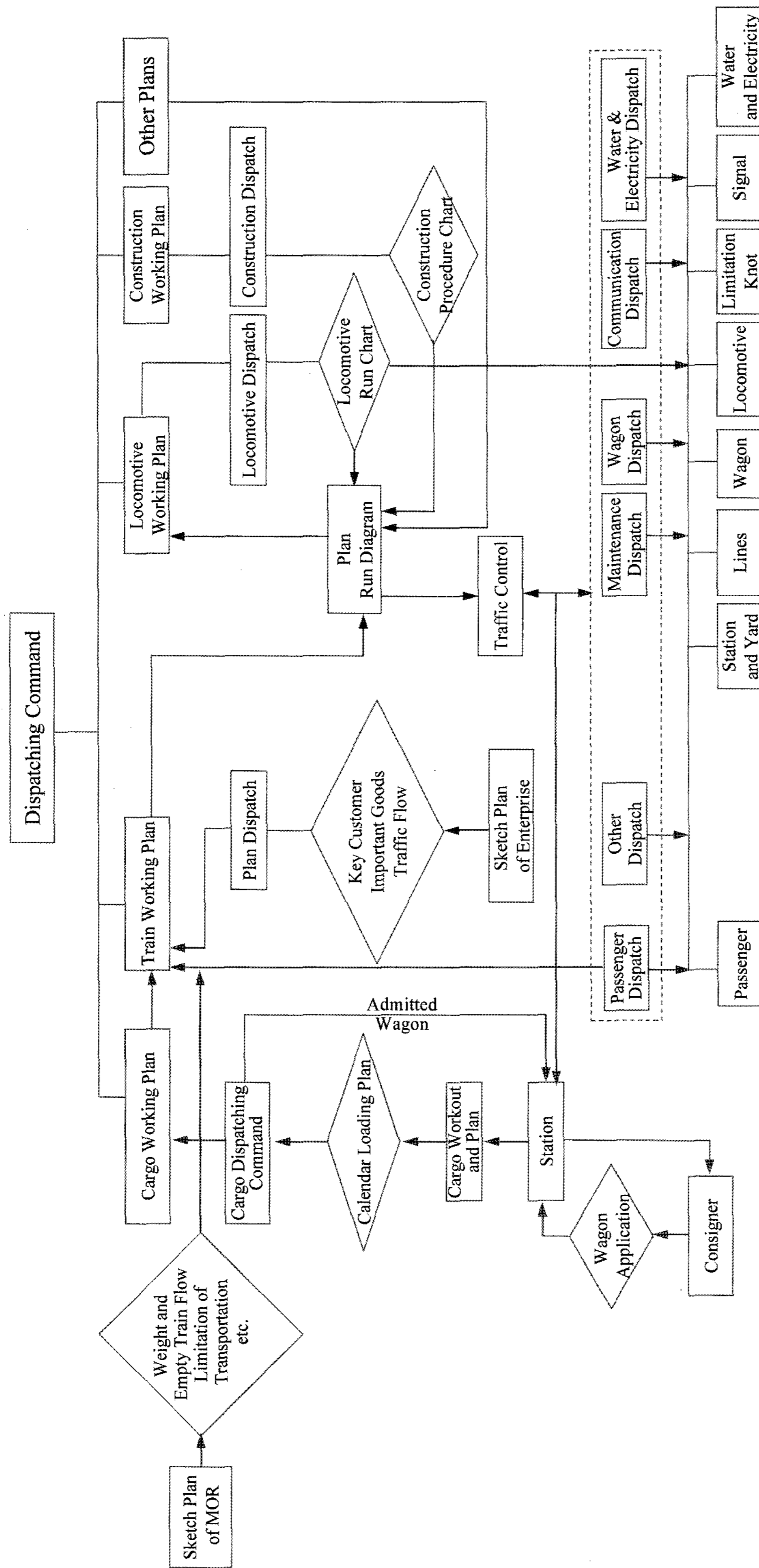


Fig. 6 Core Position and Function of Dispatch Command in Railway Transportation Production
 Note : Cited from Research task team of BJTU. Resource integration and organization optimization for Urumqi railway bureau - Exploration and summary of railway lean production[R]. Beijing Jiaotong University, 2007.2: 1-9

boundary of URB, of which, 164 lines only load and unload 4.2 wagons, or 7.6 tons per day on the average. By integrating special lines with the principle of “mass loading, mass unloading, group loading, group unloading, one-train loading, one-train unloading”, synergistic effect of enterprise special lines gradually shows up, and the efficiency of loading-and-unloading on enterprise special line, and operation performance in marshalling yard are greatly improved.

3.2.2 Transportation Process Reengineering Method

Reengineering means achieving performance optimization both in production and market positions by redesigning core business processes and supplementary business processes. Railway transportation process reengineering is to identify, redesign, and rebuild train organization process, locomotive maintenance and operation process, train condition inspection process, track maintenance process, etc. to eliminate or cancel excessive operation activities which contribute nothing to transportation production value. On the basis of cross-functional production process, organization and labor division are determined accordingly. Some comments made by Dean Wise [12] can highlight our ideas that reengineering methods proven successful with manufacturing enterprises can and should be used to rebuild railway transportation processes (cargo transportation process seen as Fig. 5) and improve railway

transportation efficiency.

Through railway transportation production process reengineering, we can find out that train is the basic organization unit for railway transportation production, thus, train organization forms the core business process, and locomotive process, cargo loading and unloading processes, and marshalling process are all supplementary ones which help to organize train with high quality. Railway transportation production process reengineering examines how work gets done by identifying, analyzing value chain, and inputs less set of production factors so as to satisfy market demand in a better way. For example, before railway LP practice, freight department in URB was in charge of wagon loading condition examination while wagon department looked after running gear, they didn't communicate and coordinate in order to find out wagons unsuitable for loading and delivery. After combination of the two departments, loading condition and running gear are checked in only one operational activity, not only activity becomes lean, but also wagon adjustment probability is reduced as well.

3.2.3 Dispatch Command Optimization Method

Dispatch command optimization is a method which aims to improve JIT production level through improvement of run diagram compiling and executing quality. The less railway transportation deviates from preset running chart,

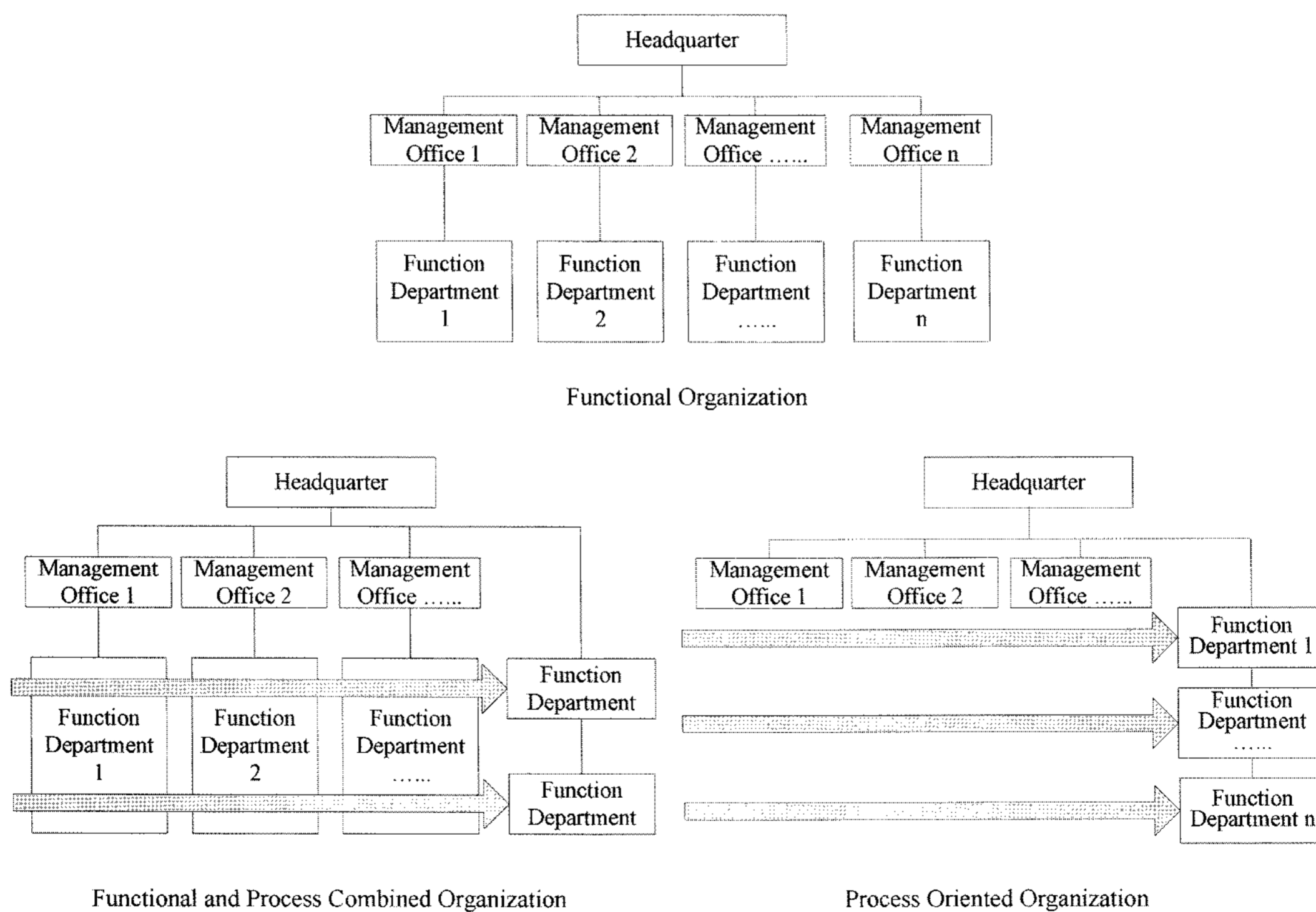


Fig. 7 Functional and Process Oriented Railway Organizations [13]

the better the punctuality and operational performance of railway production process are. It's cautious to say that dispatch command is at the core of railway LP, and plays a key role to pull the JIT production of locomotive, track maintenance, electricity, wagon, water and electricity, etc. The role of dispatch command is shown by Fig. 6.

Railway transportation enterprise implements LP with run diagram and traffic control at the center, combines train run chart, day and shift plan, and phase plan organically, transforms original inertial and stochastic railway production organization mode into a comparatively fixed plan based on railway transportation process. Through decomposition of train flow and operational activity, all the factors influencing railway transportation process from loading and unloading to marshalling are clarified to form a daily traffic control plan, shift plan and phase plan guided by run diagram in which time, line, shutting locomotive, direction, cargo category, etc. are fixed without large modification. Only dispatch command is fixed and formatted, can railway transportation LP be realized.

3.2.4 Station-zone Organization Method

Station-zone organization refers to a specific organization structure, in which, stations of certain scale are assigned with the right to coordinate, adjust and evaluate concerning productive units including traffic control, locomotive, wagon, maintenance, electricity, etc. within a certain area so that the overall object can be realized at railway bureau level. Key stations are in a dominant position and in charge of core railway business process, control key points, and reward and punish responsible production units who fully complete or fail to satisfy defined target and task. Station-zone, in essence, is a kind of process-oriented organization as shown by Fig. 7, which allocates management right and sets up organization structure according to a smooth and effective production procedure.

Station-zone is the integration unit for the production of railway transportation product where various transportation resources are integrated together to commonly create transportation service value. Different functions based on specialization division are coordinated to make production process smooth, cost-saving, safe and efficiency.

3.2.5 Railway Incentive and Constraint Mechanism Method

Railway incentive and constraint mechanism method mainly refers to performance evaluation index system whose function is to evaluate, reward and punish responsible personnel or production units. Incentive and constraint mechanism aims to break down aggregate task into small ones, clarify responsibility and right boundaries of different units or staffs, and make time standard and operational

norms clear and enforceable. During railway LP practice, URB decomposed comprehensive indexes into concrete ones including non-stop train, speed limitation, equipment failure, etc., and transportation resource and production process became controllable and managerial.

4. Lean Production Implementation Process and Effect of Urumqi Railway Bureau

Ever since 2005, according to railway LP principle as "with train flow as the masterstroke, with dispatch command as the core", URB carried out transportation resource integration and transportation organization optimization, and transportation performance indexes such as tonne volume, locomotive and wagon turnover rate, transportation income, cost expenditure etc. have been significantly improved.

4.1 Lean Production Implementation Process of Urumqi Railway Bureau

URB categorizes its transportation resources into four systems, that is, transportation organization command system (including run diagram and routine traffic control), delivery capability guarantee system (including locomotive maintenance and operation), equipment maintenance system (including track maintenance, signal equipment maintenance, and wagon equipment maintenance), and supplementary system (including electricity supply and water supply), and pulls management optimization from resource, process and product aspects, and pushes forward railway LP at railway bureau, station-zone and basic station-and-depot levels, as shown by Fig. 8 and Table 3.

During railway LP implementation process, in the first instance, Urumqi Railway Bureau put dispatch center at the dominant position, and endowed it with vertical management rights. Under direct leadership of dispatch center, there is a LP analysis office whose main duty is to make up reasonable standards and indexes according to operational characteristics of different production units so as to adjust original production pattern and customs. Secondly, station-zone is located at the middle between railway bureau and station-and-depot, and plays an intermediary coordination role. Finally, station-and-depot at the grass-root level has the right to set up detailed rules and make performance assessment about internal LP activities.

4.2 Effects of Lean Production Implementation in Urumqi Railway Bureau

By adopting LP, URB integrated transportation resources including locomotive, wagon, special line, hinge, supply of

Date	Railway Lean Production Measures and Files	Lean Production Phase
2005.3	All railway sub-bureaus were cancelled, and production power distribution was reallocated.	Overall Reform Phase
2006.1	Key Points Control Phase: -- Transportation Organization Lean Production Implementation Measures in Urumqi Railway Bureau (2006.1.19) Key Problem Tackling Phase: -- Notification about Lean Production Implementation, Transportation Potential Excavation, and Transportation Efficiency Improvement, (URB Dispatch[2006]No.216)(2006.5.12)	Process Pull Phase
2006.6	Station-zone Organization Phase: -- Urumqi West Station-zone Transportation Organization Lean Production Implementation Measures, and, Urumqi West-Station-zone Transportation Lean Production Evaluation Standards (2006.6.7) Enterprise Special Line and Hinge Integration Phase: -- Kuerle Hinge Transportation Resource Integration (2006.8.25) -- Kuerle Hinge Special Line Integration Coordination Meeting Summary (2006.12.28) -- Kuerle Hinge Transportation Organization Lean Production Implementation Detailed Rules (Kulerle Dispatch Office [2007]No.56) -- Opinions on Further Implementation of Transportation Organization Lean Production (URB Office [2007] No.4) (2007.1.26) -- Research on Feasibility of Comprehensive Management System of Alashkou Station in URB (2007.1)	Resource Pull Phase
2006.8	-- Notification of Non-stop Train Organization Method at Loading Spot (URB Dispatch [2006] No.381) (2006.8.22) -- Speech at Exchange Meeting about Transportation Organization Lean Production in URB Traffic Control System (2007.4.6) -- Speech at Lean Production Meeting in URB Traffic Control System (2007.6.10) -- Integration Plan for Urumqi North Station Traffic Control Depot (2007.7.29)	Product Pull Phase
2007.6	-- Non-stop Train Organization Panel at Loading Spot in URB (2007.6) -- Non-stop Train Organization Panel at Loading Spot in URB West Station (2007.6) -- Wagon Inspection Lean Production Further Implementation Measures (2006.11.3)	Fixed Phase

Fig. 8 Lean Production Implementation Process of Urumqi Railway Bureau

goods, and extended railway transportation process into the internal operations of customers, set up station-zone organization, built up LP measures and implementation detailed rules, improved proportion of non-stop trains, increased operational revenue, cut down production cost and made distinct achievements as shown by Table 4.

In order to verify the effect of LP of URB on transportation production efficiency, we build up linear regression model, and introduce dumb variable, that is, lean production institution into the model (1 for LP month and 0 for non-LP month), the formula and meanings of variables are shown in formula (1) and tab.5.

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \beta_6x_6 + \beta_7x_7 + \beta_8x_8 + \beta_9x_9 + \varepsilon \quad (1)$$

We collected statistical data of 36 months before and after 2006, after calculation, we find that $R=0.930$, $R^2=0.866$, $F=10.020$, significant level is 0.05, and get coefficients of the regression model as shown in Table 6.

It's obvious that railway LP has significant impact on railway operation performance by optimizing transportation indexes such as cargo sent, wagon turnover, average wagon loaded per day.

Table 3. Implementation Structure of Lean Production in Urumqi Railway Bureau

Organization Files	Railway Bureau	Administrative Office		Station-zone	Station and Traffic Control Depot	Locomotive, Wagon, Track, Signal, Water and Electricity Depot
		Dispatch Center	Other Departments			
Hami experience and relative institutions and measures	LP Strategy					
Urumqi Railway Bureau transportation organization lean production implementation measures, etc.	Assign Task	Analyze, Help and Form Evaluation Index	Make LP Implementation Rules			
Notification of lean production implementation in all station-zones, etc.		Confirm		Task Decomposition and Process Reengineering	Detailed Rules	Detailed Indexes
Lean production detailed rules for stations and depots, etc.		Station-zone Assessment			Confirm	Performance Evaluation by Station-zone
						Station, Traffic, Loco., Car, Signal, Track, Others

Table 4. Operational Indexes before and after Railway Lean Production of URB

Index	Quantity	Year			Increase Proportion
			2005	2006	
Cargo Sent (ten thousand tons)			5396	6000	+11.2%
Goods Delivered beyond Boundary (ten thousand tons)			3863	4222	+9.3%
Freight Imported and Exported (ten thousand tons)			1097	1300	+18.5%
Passenger Sent (ten thousand persons)			1134	1277	+12.6%
Wagon Turnover (day)			5.04	4.57	-9.33%
Non-stop Train (No.)			9120	12476	+36.80%
Non-stop Train Proportion (%)			50	79.8	+29.8%
Average Haulage Distance of Locomotive (kilometer)			----	638	----
Cargo Locomotive Efficiency (kilometer/loco.day)			----	624	----
Long-time-waiting Wagon (wagon/day)			350	50	-85.7%
Driver Overwork (%)			----	----	-85%
Locomotive Entering Warehouse Delay (hour)			----	----	-95%
Operational Revenue (100 million Yuan)			63.99	113.56	77.5%
Operational cost (100 million Yuan)			----	----	-29.8%

Table 5. Meanings of Variables in Multi-factor Linear Regression Model

Symbol	Transportation Index	Average	Standardized Deviation	Sample No.
y	Transportation Revenue	87597.45	7669.07	36
x ₁	Passenger Sent	97.42	20.25	36
x ₂	Cargo Sent	469.68	36.37	36
x ₃	Converted Ton-kilometer	61.67	3.99	36
x ₄	Wagon Loaded per Day	2813.95	152.23	36
x ₅	Operation Wagons per Day	17986.83	813.01	36
x ₆	Wagon Turnover	4.95	0.23	36
x ₇	Locomotive Production per Day	107.20	4.83	36
x ₈	Oil Consumption per Ten Thousand Kilometers	28.48	0.36	36
x ₉	Lean Production Institution	0.29	0.46	36

Table 6. Coefficients of Regression Model

Transportation Index	β	t	Significant Level
Constant Parameter	-136095.87	-1.297	0.016
Passenger Sent	169.96	3.244	0.006
Cargo Sent	263.16	2.808	0.014
Converted Ton-kilometer	-248.95	-0.476	0.041
Wagon Loaded per Day	-14.59	-0.709	0.090
Operation Wagons per Day	1.51	0.668	0.015
Wagon Turnover	-1762.60	-0.171	0.027
Locomotive Production per Day	-219.90	-0.813	0.030
Oil Consumption per Ten Thousand Kilometers	5090.33	1.709	0.009
Lean Production Institution	156.03	0.070	0.012

Note: For sake of business secrets, we just list the calculation results of our research group here.

5. Conclusion

Lean production originated and mainly applied to manufacturing industries whose products are tangible and measurable. It's worthy to make further discussion on whether and how lean production conception and methods could be applied to railway production. There is no doubt that the general conception and methods can be applied to railway sector. Aiming to reduce production cost as well as improve product quality to better satisfy customer needs, ordinary lean production tools including JIT production, Kanban management, flexible production, teamwork organization, etc. shed light on railway transportation integration and organization optimization so as to allocate resources efficiently. However, only combining lean production with the characteristics of railway production, can lean production play a more prominent role in railway cost reduction and value creation. The paper maintains that: (1) Lean production can effectively adapt to production process of railway transportation product and improve its punctuality. (2) Lean production can effectively coordinate complicated work division and corporation activities. (3) Lean production can effectively reduce or eliminate various kinds of uncertainty. (4) Lean production can effectively realize network economy in transportation production. At the same time, with pull management at the core, lean production consists of transportation resource integration, transportation process reengineering, dispatch command optimization, station-zone organization, railway incentive-and-constraint mechanism, and etc. Lean production practice of Urumqi Railway Bureau manifested that railway lean production endogenously improved transportation indexes and effectively lessened the intensive situation between limited transportation capacity and excessive demand through internal expansion production.

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