Study on Building Resource Availability Model in Aircraft Manufacturing Enterprises

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ABSTRACT: Based on OEE theory study, this article brings forward a resource availability model suitable for aircraft manufacturing enterprises. In such a model, a 4-level-structured model of major factors, modulation factor, index factor and lost time is established based on the study on items affecting equipment resource input efficiency, and index factor determination principles and lost time assignment methods are analyzed. Depending on the impact degree exerted by index factors, three availabilities are defined, and the computing process of various availabilities of equipment resources based on such availability model in an enterprise is exampled.

Keywords: availability, equipment resource, availability model, building

1. Introduction

Capacity, i.e. manufacturing capability, refers to the maximum quantity of products or raw materials of certain type and with certain quality which are manufactured or processed with an enterprise's all productive fixed assets and within a period of time after an overall balance and under certain technical and organized condition. The definition of capacity can be understood from static and dynamic perspective. From the static perspective, capacity corresponding with the capabilities provided by an enterprise in unit time, shall be the theoretical manufacturing capabilities owned by an enterprise, and is the expected output capabilities with an enterprise's manufacturing resources. It depends on the resources with which products are manufactured on process lines, and it is also called resource availability. From the dynamic perspective, capacity corresponding with actual output of certain products manufactured by an enterprise in unit time, is the actual manufacturing of certain products in the current organization mode and under current technical condition of an enterprise[1].

Capacity evaluation is an effective approach[2] to systematically identify and evaluate production process control, equipment use and management level of an enterprise. Proper evaluation on production capacity by a manufacturing enterprise provides a proper basis for capacity decision, affiliates proper use of various resources, scientifically make production schedule, effectively control production processes and improve the enterprise's response capability and competitiveness. Proper allocation of production resources to produce certain quantity of products may lead to full use of an enterprise's limited production resources and maximize production efficiency.

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At present, both domestic and foreign study on capacity evaluation in discrete manufacturing enterprises mainly focuses on capacity estimation at a dynamic level, and is used to analyze the match-up of supportive manufacturing capacity and task-demanding capability. The result of such evaluation is mainly used for "rough" capacity balance and makes insufficient analysis and diagnosis on overall operation effectiveness of systems and resources. This article, on the basis of current situation in aircraft manufacturing enterprises, brings forward an availability evaluation model with calculation of rated output capabilities of resources as the goal so as to cover the insufficient capacity evaluation by the discrete aircraft manufacturing enterprises.

2. Categories of Manufacturing Resources

Availability is built on the basis of an enterprise's basic manufacturing resources. At certain production and technical level and in certain production scale, the resources affecting availability include equipment, personnel, facilities, sites, materials, etc[3]. This article mainly studies the availability of equipment resources that affect aircraft product output. For the convenience of calculating production capacity, an extended three-dimensional production capacity space model is set up in three aspects of organization, calendar and resources, as shown in Figure 1.

Manufacturing resources exist in production organizations at all levels, and the availability generates an accumulation effect between the upper and lower levels of production organization. Generally speaking, the production organization of manufacturing enterprises includes production lines, production units, work shops, factories, and companies, etc. from bottom to top. Time dimension refers to the natural time and calendar time directly or indirectly developed and utilized by personnel and equipment during production operations. In order to improve the consistency, coordination and balance of production capacity, different production organizations of enterprises adopt different work calendars. With certain production efficiency of personnel and equipment, the effective working time of the calendar is the main factor affecting production capacity.

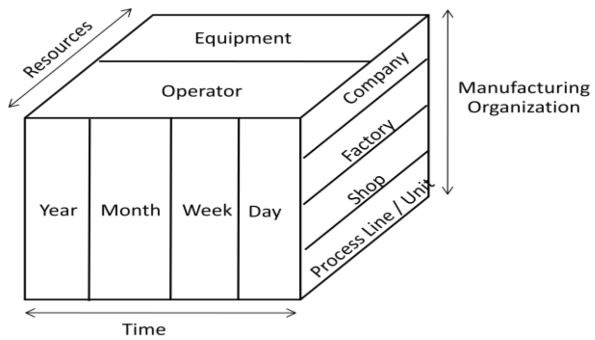

Figure 1 Organization, Calendar and Resource Model

3. Problems existing in capacity evaluation of aircraft manufacturing enterprises

(1) Lack of systematic analysis and evaluation

Most enterprises' capacity evaluation is based on man-hour method, which analyzes the output quantity of final products produced on process lines, and makes estimation on the single-dimension output, which can support the match-up analysis on between actual capacity and task-demanded capacity. However it may lead to the insufficient analysis and diagnosis on OEE of manufacturing resources.

(2) Lack of effective supporting data

Most enterprises lack of reliable data for capacity evaluation, so quantitative capacity analysis is hardly performed. It becomes a common practice to make qualitative estimation on the basis of experiences, which results in inaccurate evaluation on production capacity, resulting in the deviation between production capacity required by production plan and actual production capacity of the enterprise. The evaluation results can only be used for "rough" capacity balance.

(3) Lack of applicable evaluation model

Due to lack of basic data accumulation, most enterprises carry out linear calculation based on quota man-hours, production plan outline and other data. They are lack of applicable capacity analysis and calculation model, and lack of quantitative analysis and evaluation methods for production capacity elements and manufacturing resources.

4. OEE Calculation and Analysis

OEE is the percentage of time used to manufacture acceptable parts by measuring equipment and its specified capacity. It is a part of overall production maintenance and measures the performance of the entire manufacturing process [4-5]. OEE method can identify the efficiency loss of equipment in each process and release the hidden or lost capacity [6-7].

4.1OEE Index Analysis

OEE consists of three performance indicators used to measure equipment performance: availability rate, performance rate, and quality rate. OEE= availability rate × performance rate × quality rate with their relationship shown in Figure 2.

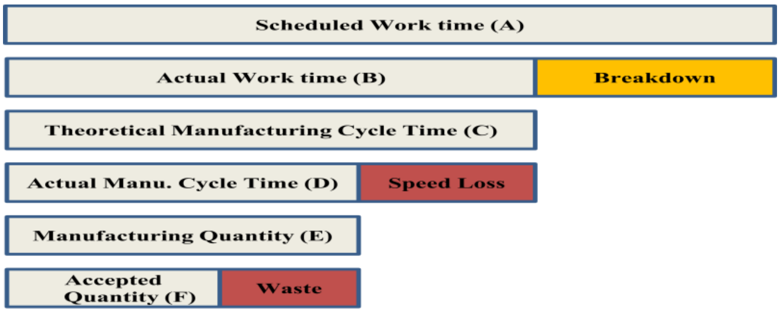

Figure 2 Relationships between Time Loss and OEE

1) Availability Rate. Availability rate = (actual working time B/planned working time A) ×100%. Availability rate is used to calculate the cost caused by shutdown, including any event resulting from planned production shutdown, such as equipment fault, tool damage and replacement, material shortage and other major failures, or emergency shutdown events.

2) Performance Rate. Performance rate is the ratio of actual processing cycle and theoretical processing cycle, that is, performance rate = (actual processing cycle D/ theoretical processing cycle C) × 100%. It reflects equipment performance, including any factor that causes the equipment to work below the designed capacity, such as equipment downtime, unacceptable intermediate tests, equipment cleaning, inspection, adjustment, etc.

3) Quality Rate. Quality rate is the ratio of acceptance quantity to production quantity. Quality rate = (quantity of acceptable product F/ produced quantity E) ×100%. It reflects the effective operation of equipment and refers to the loss of productivity due to quality issues, such as, product loss before formal operation of equipment, product loss during formal operation of equipment.

4.2Time Loss Factor Analysis of OEE

OEE classifies the main loss of equipment efficiency into six categories according to its three types of elements, including shutdown loss, replacement and adjustment loss, suspension loss, speed reduction loss, starting defective goods loss and producing defective goods loss, as shown in Table 1.

Table 1 Examples of OEE Time Loss

Time Loss Events	OEE Measurement	Time Loss Classification	Examples of Time Loss Classification
Equipment Failure	Availability Rate	Failure Time	Equipment failure, tool damage, unplanned maintenance
Equipment Adjustment/Setting	Availability Rate	Failure Time	Manufacturing preparation, equipment switching, material shortage

Equipment Shutdown	Performance Rate	Rate	Wrong handover of products, assembly jamming, logistical disruption
Equipment Speed Reduction	Performance Rate	Rate	Operator level, service life, tool wearing
Poor Equipment Startup	Quality Rate	Quality	Tolerance adjustment, equipment warm-up process, damage
Equipment manufacturing is not acceptable	Quality Rate	Quality	Improper assembling, scrap and rework.

4.3Examples of OEE Calculation

As per the basic theory of OEE, elementary calculation shall be conducted on the basis of Table 2 Examples of Each OEE Item and Time Assignment.

Table 2 Examples of OEE Items and Time

Items	Time (min.)	Definitions
Shift Time	480	Working time per shift
Operating Time	375	Total operation time per shift
Break Time	60	Total break time per shift
Failure Time	30	Total fault time of each shift
Setup Time	15	Total set time of each shift
Total Quantity of parts	360	Total part quantity of each shift
Quantity of acceptable Parts	355	Quantity of acceptable parts per shift
Target Quantity	400	Predicted quantity of parts per shift

See Table 3 for Process Time and Calculation Formula.

Table 3 Process Time and Calculation Formula

Process Data	Formula	Time(min.)
Operation Time	Total manufacturing time of equipment	375
Total Time	Failure time +operation time + setup time	420
Quantity for Acceptable Parts	Quantity of acceptable parts manufactured by equipment	355

Calculation result and formula are shown in Table 4.

Table 4 OEE Calculation Result and Formula

OEE Variable	Formula	Result
Availability Rate	Operation Time/Total Time (375/420)	89.29%
Performance Rate	Quantity of All Parts/Target Quantity (360/400)	90.00%
Quality Rate	Quantity of Acceptable Parts/Quantity of All Parts (355/360)	98.61%
Overall Equipment Effectiveness (OEE)	Availability Rate × Performance Rate × Quality Rate	79.24%

5. Resource Availability Model

Taking the theory of Overall Equipment Effectiveness (OEE) as reference, this article constructs the availability model of equipment resource, and calculates the expected output capability produced by the equipment based on the resource availability model.

The general idea is to take OEE as the basis, combine with the characteristics of aircraft manufacturing enterprises, and specifically detail, identify and classify the main factors impacting the effectiveness of time, performance and quality, and form the availability model for a single type of equipment.

5.1Modulation Factor of Availability

Modulation factor is to classify the events (indicator factors) impacting resource capacity as per the association level of relevant activities and product manufacturing. There are 3 levels: Standard Relaxation, Proper Relaxation and Extended Relaxation.

1)Standard Relaxation: It refers to the non-value-added time caused by auxiliary activities regularly occurring or certain events during equipment use an operation process, which are related to product manufacturing processes, and have fixed working procedure, such as equipment check before start-up;

2)Proper Relaxation: It refers to the non-value-added time caused by auxiliary activities occurring usually or uncertain events during equipment use and manual operation, which are related to product manufacturing process and have relatively fixed working procedures, such as equipment maintenance;

3)Extended Relaxation: It refers to the non-value-added time caused by auxiliary activities occurring occasionally or uncertain events during equipment use and manual operation, which are related to product manufacturing process and have unfixed working procedure, such as equipment failure and breakdown.

5.2Index Factor of Availability

Indicator factor further details availability rate, performance rate and quality rate, and refers to the time consumed by the capacity of non-value-added equipment or personnel in working hours of each day or each shift. Indicator factors are determined by comprehensive analysis on events affecting equipment and operator productivity in the first three years since their occurrence and are divided into three kinds of relaxation: standard, proper and expansion, such as physiological needs time (drinking water, going to the bathroom), downtime (pre-shift meeting, work arranging) and idle time (tooling waiting time, program invocation time).

5.3Time Value of Indicator Factor

Time value of indicator factor is, by making statistics on big data, the average probability time caused by the activities of target resources in the past three years. It is the operation or activity time value of daily routine, normal production and preparation of "people" and "equipment" resources under the condition of shutdown and production without considering irresistible factors. Among them, the capacity consumption time of equipment or personnel caused by multiple or accidental events shall be averaged by the annual total amount and equally shared by the time of each day and shift. Data are calculated by the average time of each event per person, per day and per shift.

5.4Types of Availabilities

To sum up, availability model is composed of main indicators, modulation factors, indicator factors and relevant time loss values. Accordingly, for the same type of equipment, the availability can be calculated and analyzed into value-added capacity, standard capacity and proper capacity and the calculated result is available time.

1) Value-added capacity: the ability to directly process, inspect or test products, i.e. the actual effective online running time of equipment or personnel.

2) Standard capacity: the probability time of occurrence of each event taken into account, which strictly conforms to the lean process of production operation. On the basis of value-added capacity, the waiting time of equipment or personnel caused by necessary production preparation or physiological demand is included.

3) Proper capacity: on the basis of standard capacity, consider the probability time of occurrence of various events, including the waiting time of equipment or personnel caused by multiple or accidental events on the production line.

5.5Equipment Availability Model

Based on the analysis above, availability model for equipment resources is shown in Table 5:

Table 5 Example of Equipment Availability Model

Main Factors	Modulation Factor	Indicator Factor	Time		
			Equipment 1	equipment 2	......
Basic Situation		Routine working time per day	-	-	
		Working days per month	-	-	
		Average work time per shift	-	-	
		Work shift per day	-	-	
		Operator quantity per shift	-	-	
		Operator quantity per equipment	-	-	

Availability Rate	Standard Relaxation	**XXX**	-	-	
		....	-	-	
	Proper Relaxation	**XXX**	-	-	
		....	-	-	
	Extended Relaxation	**XXX**	-	-	
		....	-	-	
	Effective Time	**Value-added effective operation time**	-	-	
		Standard effective operation time	-	-	
		Proper effective operation time	-	-	
	Effectivity	**Value-added effectivity**	-	-	
		Standard effectivity	-	-	
		Proper effectivity	-	-	
Performance Rate	Standard Relaxation	**XXX**	-	-	
		....	-	-	
	Proper Relaxation	**XXX**	-	-	
		....	-	-	
	Extended Relaxation	**XXX**	-	-	
		....	-	-	
	Effective Time	**Value-added net operation time**	-	-	
		Standard net operation time)	-	-	
		Proper net operation time	-	-	
	Effectivity	**Value-added effectivity**	-	-	
		Standard effectivity	-	-	
		Proper effectivity	-	-	
Quality Effectivity	Standard Relaxation	**XXX**	-	-	
		....	-	-	
	Proper Relaxation	**XXX**	-	-	
		....	-	-	
	Extended Relaxation	**XXX**	-	-	
		....	-	-	
	Effective Time	**Value-added full production time**	-	-	
		Standard full production time	-	-	
		Proper full production time	-	-	
	Effectivity	**Value-added quality effectivity**	-	-	
		Standard quality effectivity	-	-	
		Proper quality effectivity	-	-	
Overall Equipment Effectiveness (OEE)		**Value-added OEE**	-	-	
		Standard OEE	-	-	

	Proper OEE	-	-	
Availability (per day)	Proficiency	-	-	
	Value-added capacity	-	-	
	Standard capacity	-	-	
	Proper capacity	-	-	

The measurement shall be made per month, and the calculation formula of various capacities is as follows:

Value-added capacity = (working time per day × working days per month × shifts per day × value-added OEE) ×operators' proficiency

Standard capacity = (working time per day × working days per month × shifts per day × standard OEE) ×operators' proficiency

Proper capacity = (working time per day × working days per month × shifts per day × proper OEE) ×operators' proficiency

Quantity of index factors in the model shall be categorized on the basis of process line situation. Each index factor shall be determined as per the actual condition. The time value of each index factor requires accurate statistics and calculation by means of scientific approaches so as to obtain accurate and reliable availability data.

The availability model of equipment resources can be used to calculate the availability of a single equipment resource in one working calendar day. In case of multiple sets of equipment of the same type within one manufacturing organization, the availability in one working calendar day can be added together for calculation. Such addition is also applicable to the calculation of availability in a week, month, quarter or year. However, for the equipment used in different manufacturing organizations, the availabilities cannot be added together. The availability shortage shall be calculated for each specific organization and equipment type (work center) in line with demanded load capacity of such organization and equipment.

6. Examples of Availability Calculation

Based on the availability model, the statistics is made on the 3 types of loss time data for the 2 types of equipment on certain process line, and 3 availabilities are calculated. Basic data and calculation example is shown in Table 6.

Table 6 Example of Equipment Availability Model Calculation

Main Factor	Modulation Factor	Index Factor	Time (in minute)	
			Equipment 1	Equipment 2
Basic Situation		Routine work time per day	480	480
		Work days per month	21	21
		Average work time per shift	480	450
		Work shift per day	1	2
		Operator quantity per shift	5	5

		Operator quantity per equipment	1	1
Availability Rate	Standard Relaxation	daily rest	15	15
		Toilet time	10	10
		Equipment cleaning	8	10
		Work uniform change	5	5
	Appropriate Relaxation	Pre-shift meet	10	10
		Learning and training	10	10
		Audit/inspection preparation	5	7
	Extended Relaxation	Tooling awaiting	13	13
		Meeting awaiting	5	5
		Private affairs dealing	10	12
	Effective Time	Value-added effective run-time	389	353
		Standard effective run-time	427	393
		Proper effective run-time	452	420
	Efficiency	Value-added efficiency	81.0%	78.4%
		Standard efficiency	89.0%	87.3%
		Proper efficiency	94.2%	93.3%
Performance Rate	Standard Relaxation	Equipment inspection/adjustment	3	5
		Program callout/verification	2	2
		Tooling, cutters and gauges preparation	10	10
		Blank/raw material preparation	5	5
		Part loading and unloading	4	5
	Proper Relaxation	Equipment maintenance	3	5
		Equipment cleaning time	4	4
		manufacturing recording time	2	2
	Extended Relaxation	Idle/waiting time	3	3
		Equipment malfunction shutdown	5	5
		Technical problem handling wait	5	5
	Valid time	Value-added net uptime	343	302
		Standard net uptime)	405	369
		Appropriate net uptime	439	407
	Validity	Value-added validity	88.2%	85.6%
		Standard validity	94.8%	93.9%
		Appropriateness validity	97.1%	96.9%
Quality Effectivity	Standard Relaxation	Inspection of profile/dimension	6	8
	Proper Relaxation	Rework/Repair	7	9
	Extended Relaxation	Scarp and new fabricate	1	3
		Out-of-tolerance processing wait	3	3
	Valid time	Value-added full production time	326	279
		Standard full production time	394	354
		Proper full production time	435	401
	Validity	Value-added quality efficiency	95.0%	92.4%

		Standard quality efficiency	97.3%	95.9%
		Proper quality efficiency	99.1%	98.5%
Overall Equipment Effectiveness (OEE)		Value-added OEE	67.9%	62.0%
		Standard OEE	82.1%	78.7%
		Proper OEE	90.6%	89.1%
		Proficiency	1.0	0.9
Availability (per day)		Value-added capability	326	502
		Standard capability	394	637
		Proper capability	435	722

Similarly, in the research of this project, an availability model is established on the basis of availability model of equipment resources for the corresponding operators engaged in periodic operations, which realizes the calculation of availability of personnel in various organizations. Different from equipment resources model, index factors of operators shall be more suitable for various time losses in work process of personnel of different organizations.

7. Conclusion

Capacity evaluation and calculation of aircraft manufacturing enterprises is a complex and systematic project. By establishing resource capacity model, the availability of various resources in an enterprise's organization of all levels can be quantitatively evaluated and calculated within each evaluation cycle, the issue of accurate calculation of resource availability in discrete aircraft manufacturing enterprises is solved. Meanwhile, various data calculated with resource availability model can be used for comprehensive diagnosis and evaluation on the application management efficiency of the enterprise organization of all tiers and resource, and provides the essential data for enterprises to solve specific management problems and improve operation efficiency.

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