

and the heterogeneity of the work content. Thus, specific processing sequences have an impact on the mean number of orders on a workstation ( $WIPO_m$ ) and with that also the mean virtual throughput time. By applying the SOT rule (SOT: shortest operation time) orders with less work content are prioritized for processing. As a result, fewer orders on average are found on the system, therefore the mean throughput time is also low. Conversely, in applying the LOT sequence (LOT: longest operation time) orders with large work content are prioritized and many small orders have to wait. Consequently the  $WIPO_m$  and the virtual throughput operation time  $TTP_{vir}$  are correspondingly higher/longer. The greater the work content's variance is, the more prominent the effects are.

In contrast, these factors have no influence in the Funnel Formula. With the given input and a sufficiently long reference period, the WIP (in planned hours) and consequently the range, can only be influenced by the system output: Neither the sequence of the processing nor the distribution of the work content have an impact.

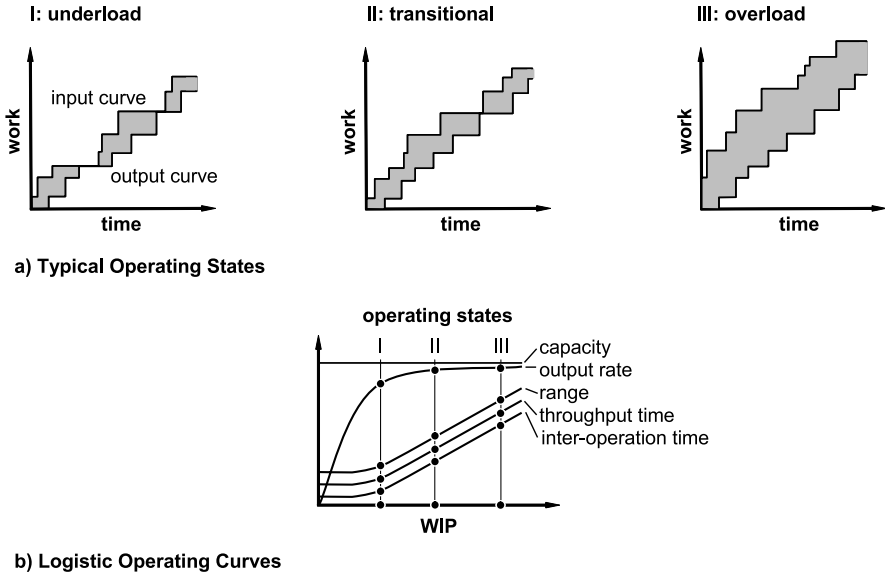
## 2.4 Logistic Operating Curves for Production Processes

Using the performance figures and diagrams introduced above, fundamental information can be gained about a production system and applied in order to analyze a variety of problems. Tracing the causes of scheduling deviations and deriving appropriate control measures is thus extensively supported. The interactions between the logistic parameters however is only partially described when at all. The following questions thus remain unanswered:

- What is the lowest throughput time that can be attained given the present processing and order structures?
- How high does the WIP level have to at least be in order to avoid a loss of output?
- What potential for improvement can be developed with which measures?

Here, *Logistic Operating Curves* (LOC) can be helpful. Logistic Operating Curves depict the correlations between the logistic objectives: output rate, throughput time, inter-operation time and range, as a function of the WIP. Due to the central importance of the LOC we will explain them in detail in the following.

The Funnel Model, the Throughput Diagram and the performance figures that result from them describe a specific stationary operating state. In Fig. 2.11a, three fundamentally different operating states are shown in simplified Throughput Diagrams. These different operating states can now be aggregated and depicted in the form of Logistic Operating Curves (Fig. 2.11b). To accomplish this, the output rate and the three throughput time parameters are plotted as a function of the related WIP. The Output Rate Operating Curve (OROC) indicates that the output rate of a workstation only changes negligibly above a specific WIP level. From this point on, there is continuously enough work available to ensure that there are



**Fig. 2.11** Representation of Different Operating States in Logistic Operating Curves

no WIP dependent breaks in production. Below this WIP level however, there are increasing losses due to the intermittent lack of work in the queue. The (un-weighted) throughput time though, generally increases above this critical level proportional to the WIP. When the WIP levels are reduced, the throughput time decreases. Nevertheless, the throughput time cannot fall below a minimum level derived from the order's mean operation time and where necessary, transport time. The Inter-Operation Time Operating Curve (ITOC) generally exhibits a similar behavior, approximating the transport time when the WIP levels are low. Finally, the Range Operating Curve (ROC) is derived according to the Funnel Formula, from the ratio of the WIP to output rate.

It should be pointed out that the momentary status of a system always corresponds to only one operating point on the Logistic Operating Curve. The LOC represent how the observed system with otherwise unchanged boundary conditions behaves when a different WIP level is set. They thus characterize the logistic behavior of a production process when the WIP level changes. Moreover, it is also possible to create Logistic Operating Curves for different production or order structures, to compare them with each other and to thus assess the impact of interventions on the production process from a logistic perspective.

It can easily be seen that the general form of the Logistic Operating Curves is applicable to any production system: Reduced WIP levels lead to reduced throughput times, but can also lead to material flow disruptions and thus to losses of utilization. Nonetheless, the specific shape of the LOC for the corresponding observed workstations are dependent upon the various boundary conditions such

as the capacity, the orders that are to be processed (in particular their mean and variability) and how the system is integrated into the material flow.

For obvious reasons it is not possible to determine the LOC through a series of tests in an actual plant. On the one hand, this is because of the costs that accumulate when the WIP levels are extremely high or extremely low. On the other hand, due to changes in the structural conditions (e. g., a change in the product or order mixture) no comparable ratios result and thus, the individual operational states can also not be directly compared.

As mentioned in the introductory remarks, it is clear that in such cases models that can emulate the original system of interest should be implemented. In the next chapter we will describe and analyze three models that describe the correlations between the relevant logistic objectives and thus can help solve the dilemma of operations planning. Two of these, queuing theory and simulation, are traditional models; we will illustrate the possibilities and limitations of these model applications in the following. Subsequently in Chap. 4, we will introduce a new method for calculating Logistic Operating Curves using an approximation equation.



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