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APPLYING DISCRETE EVENT SIMULATION AND AN AUTOMATED BOTTLENECK ANALYSIS AS AN AID TO DETECT RUNNING PRODUCTION CONSTRAINTS

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ABSTRACT

Discrete event simulation is an important decision support tool to evaluate changes in manufacturing, distribution or process facilities. The challenge arises when it comes to the integration of simulation as an effective tool to detect manufacturing constraints and to suggest improvement alternatives. This paper describes the application of a method for detecting bottlenecks in discrete event models developed by Toyota Motor Company. The objective in this case is to automate the bottleneck analysis facilitating the understanding and adoption of simulation by decision makers without knowledge of simulation. The main results of this paper are the validation of the bottleneck detection method and its integration with MS Excel spreadsheets. Moreover system improvement alternatives are presented by the use of design of experiments.

1 INTRODUCTION

The production system located at Volvo Car Corporation (VCC) in Torslanda, Sweden is divided according to Figure 1.

Figure 1: Volvo Cars Plant in Torslanda, Sweden

The Flow Simulation Department at Volvo Car Torslanda (VCT) is responsible for simulation studies concerning both running production and design of new manufacturing facilities or processes. Fairly detailed simulation models have been developed for each part of the plant in order to provide answers to all kind of requests which can be related to production flow optimization or bottleneck analysis. Since these detailed simulation models aim to be virtual replicas of the existing manufacturing system, they are also referred to as full blown models.

Due to the complex nature of full blown models, they can only be operated by experienced simulation engineers. Nevertheless, according to Jägstam and Klingstam (2002), the role of the user of simulation models will probably move away from the expert to the executive. Thus, the simulation models must become easier to use.

Moreover, there is a necessity to reduce the long study time to analyze simulation results. Therefore the development of new work methods concerning flow simulation, which aim to reduce the analysis phase and also to integrate the decision makers into this process, can substantially increase the adoption of discrete event simulation (DES) as a tool for selecting improvement projects in running manufacturing systems.

The objective of this study is to suggest the application of a practical bottleneck detection method, which can easily pinpoint constraints in manufacturing systems, and utilize design of experiments (DoE) to seek for improvement alternatives in discrete event models.

2 BACKGROUND

Nowadays at VCT, the bottleneck analysis carried out with DES utilizes either the *average waiting time* detection method or the *utilization* detection method.

The *average waiting time* detection method calculates the average time a workpiece spends in a queue until it is processed by a station. The stations where the workpieces wait for the longest time are the ones considered bottlenecks.

The *utilization* method measures the percentage of time a station is in its active state. Therefore a station with the highest active percentage is the bottleneck. Roser, Nakano, Tanaka (2001) state that as both working times and repair times can constrain the system, the *utilization* method should consider the working and repair percentages. This is defined as active utilization.

According to Roser et al. (2001), both methods have several drawbacks. While the *average waiting time* in a queue is compromised when the system contains buffers of limited size, the *utilization* method may point out stations with similar active percentages. Therefore it is difficult to distinguish the primary bottleneck with relative confidence.

In addition, the alternatives of improvements in order to eliminate the bottleneck are investigated using the 'one factor at a time' analysis instead of applying design of experiments (DoE). According to Pyzdek (2001) the drawbacks of this approach are:

- It is usually impossible to keep all other factors constant.
- There is no way to account for the effect of joint variation of independent factors, such as interaction.
- There is no way to account for experimental error, including measurement variation.

Therefore a lot of time is consumed during the analysis of the simulation outputs. It is also sometimes unclear to the decision makers which steps should be undertaken in order to improve their manufacturing systems.

3 PRACTICAL BOTTLENECK DETECTION METHOD

Roser et al. (2001) at Toyota Motor Company have developed a bottleneck detection technique that can be easily implemented in DES models independently of the manufacturing system structure. In order to apply the method it is necessary to identify which station changed its status at what time. Therefore a list of all possible discrete states for a station has to be created. A station, for instance, may be working, starving, being repaired, changing tools or blocked. Once all possible discrete states are listed, they have to be grouped into active or inactive states. A state is inactive if the associated station is waiting for the arrival of a workpiece (starving), or for the removal of a workpiece (blocked). On the other hand, a state is active whenever it is not inactive.

In order to identify a bottleneck, Roser et al. (2001) measured the duration of the periods in which the station is active and calculated its average. The equations are presented in Roser et al. (2001).

Roser et al. (2001) states that *the machine with the longest average active period is considered to be the bottleneck, as this machine is least likely to be interrupted by other machines, and in turn is most likely to dictate the overall system throughput.*

4 SYSTEM DESCRIPTION

The car manufacturing plant at VCT produces three models of cars: XC90, S80 and V70. The car bodies of XC90 and S80/V70 models are produced separately in two main production flows as illustrated in Figure 2. The focus of this paper is on the under body (UB) process of the XC90 production flow in the body shop.

Typically, a body shop consists of three major processes: under body, framing and assembly.

- *Under body*: In the first step the floors of the three types of cars are assembled in three areas: UB1 (S80), UB2 (V70) and UB5 (XC90). The floor is divided into three main parts: front floor, central floor and rear floor, which are assembled to a complete floor. The completed floor enters into the floor lines, where some additional reinforcements are added. Finally, the quality of the under body is checked before entering the framing area.
- *Framing*: There are two framing areas – one for XC90 and one for S80/V70 models. In each area, four main parts are connected to each other: floor, left side body, right side body and roof. Afterwards, the upper body structure is welded by robots. Finally, the body is measured and audited before entering into the final assembly area.
- *Assembly*: The XC90 bodies are assembled separately from the S80/V70 bodies. In each of the assembly areas the body is welded both manually and by robots. After welding fenders, doors, hood and trunk lid, the complete bodies of all models are audited in the finishing area, and then forwarded to the paint shop.

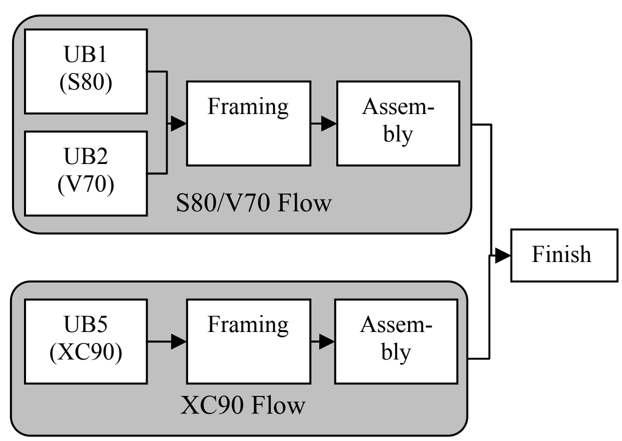

Figure 2: Body Shop at VCT

A flow chart illustrating the under body process of the XC90 production flow (UB5) is presented in the Appendix.

4.1 Methodology

The framework of this simulation project followed the steps that can be found in Banks (1998); Law and Kelton (2000) and is summarized in Figure 3.

During the system definition phase the simulation objective and the scope of the project were defined. The aim was to develop a simulation model of the UB5 area whereby a practical bottleneck method could be applied reducing, on one hand, the time for the analysis phase while, on the other hand, giving a better visibility of potential areas for improvements to decision makers.

Data collection and model conceptualization were carried out in parallel during the conceptual model phase. The necessary input data had to be collected through different sources of information within VCT. In order to simplify and screen the universe of input data that could be used in this project the conceptual model was built at the safety area level. By definition a safety area consists of several stations, which will be turned off, if one of them gets into failure mode. A production line or a subsystem can be seen as a group of connected safety areas. Disturbance data such as mean time to failure (MTTF) and mean downtime (MDT) were gathered and reckoned at the safety area level. Time to failure has negative exponential probability density function while downtime has lognormal probability density function. Real cycle times for each safety area were also collected. Organizational related losses such as raw material availability and operator disturbances were not included in this case study.

The following steps were the implementation of the conceptual model, its validation and verification, and finally application.

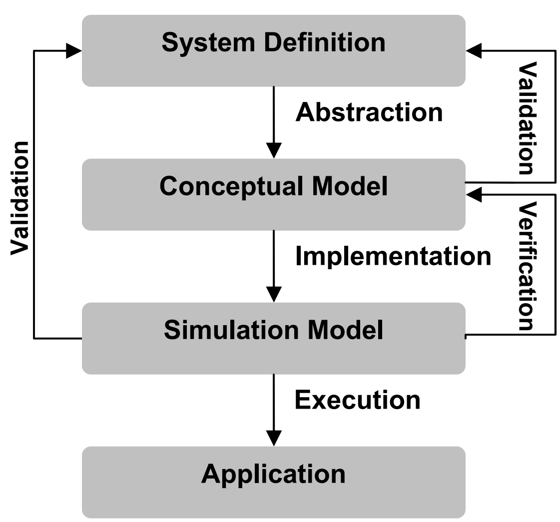

Figure 3: Simulation Project Methodology

In the application phase a Plan-Do-Check-Act (PDCA) cycle described by Bergman and Klefsjö (2003) was applied as a problem solving methodology. As shown in Figure 4, the DES model is initially used to quickly identify problem areas (e.g. bottlenecks) in the production flow by conducting a first set of experiments. As a result an improvement team can be formed to focus on this problem area. Hence, a second set of experiments is designed with the help of design of experiments (DoE). Once the improvement alternatives are identified, they have to be implemented. Therefore the improvement team has to study whether the improvement actions are working or not. If the improvement steps taken were successful, the new and better quality level should be made permanent. If there is no success, the cycle has to be followed once more.

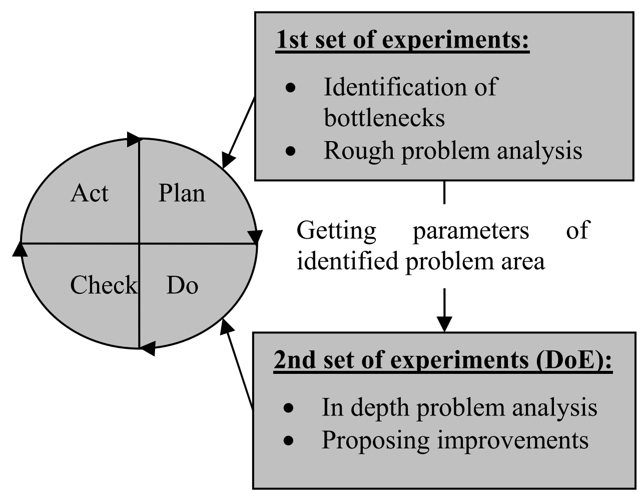

Figure 4: Effective Integration of a Simulation Model in the Improvement Cycle

4.2 Simulation Model

A simulation model was constructed using the simulation software Extend 5.0.7 in connection with MS Excel (Krahl 2003).

The warm-up period was set to 8 days. All output measures were collected during 30 days. Therefore each simulation run had a total length of 38 days. A replication/deletion approach was used to analyze the output measures. A total of 5 replications were needed in order to achieve the desired statistical confidence.

A module to measure the average active state duration of each safety area was developed in Extend. Besides that, all the output measures are sent to a MS Excel spreadsheet and structured in a way that the decision makers can easily identify the production bottlenecks.

5 BOTTLENECK IDENTIFICATION

Figure 5 illustrates the result achieved applying the practical bottleneck detection method developed by Roser et al. (2001). As one can see the safety area 5 is pinpointed as the primary bottleneck, as it has the highest average active period, with excellent confidence while safety areas 1 and 2 are the secondary ones.

This method allows a fast identification of primary bottleneck with good accuracy. The manufacturing structure of the safety areas presented in Figure 5 is illustrated in Figure A-1 in the Appendix.

In addition, an analysis of the running production data have also confirmed the safety area 5 as the primary bottleneck.

The subsequent step was to execute a DoE to validate the bottleneck identification method and draw out suggestions for improvements.

6 DESIGN OF EXPERIMENTS

Looking at Figure 5, a problem area was defined in the UB5 section. Safety areas 5, 2 and 1 were selected in order to scope the problem and the factors to be scrutinized. As those safety areas constrain the manufacturing system, critical parameters related to them were selected in order to execute a DoE.

Moreover, a buffer was placed immediately after the safety area 5 to analyze to what extent the throughput of the system or cars produced per hour (JPH) would be improved. This was a request issued by the decision maker or customer of this project.

Figure 6 shows the input factors selected for the DoE in the form of an Ishikawa diagram.

A two level fractional design was planned with resolution 4. This resolution was chosen as two factor interaction is not confounded with one factor. This gives a total of 16 experiments. Three more experiments with centre points were added making it possible to estimate the error in the experiments without using replication. It also enabled the analysis of quadratic behaviour in the input factors as stated by Myers and Montgomery (1995).

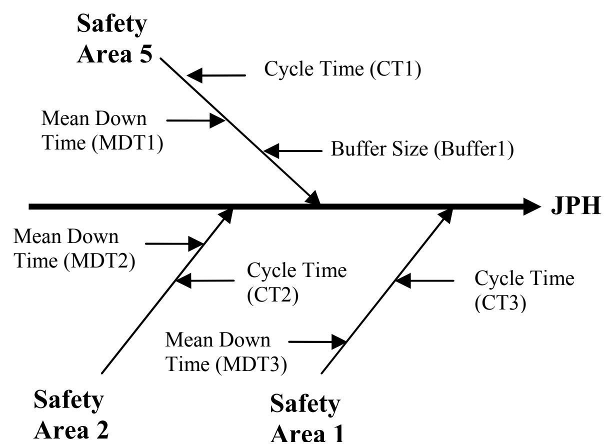

Figure 6: Input Factors for DoE – Ishikawa Diagram

The low level for cycle times was set 20% lower than the values observed in reality, while the high level was set 20% higher. For mean down times the low level was set 50% lower than the reality and 50% higher for the high level. The low level for the buffer capacity placed after safety area 5 was 0 units and the high level was 4 units.

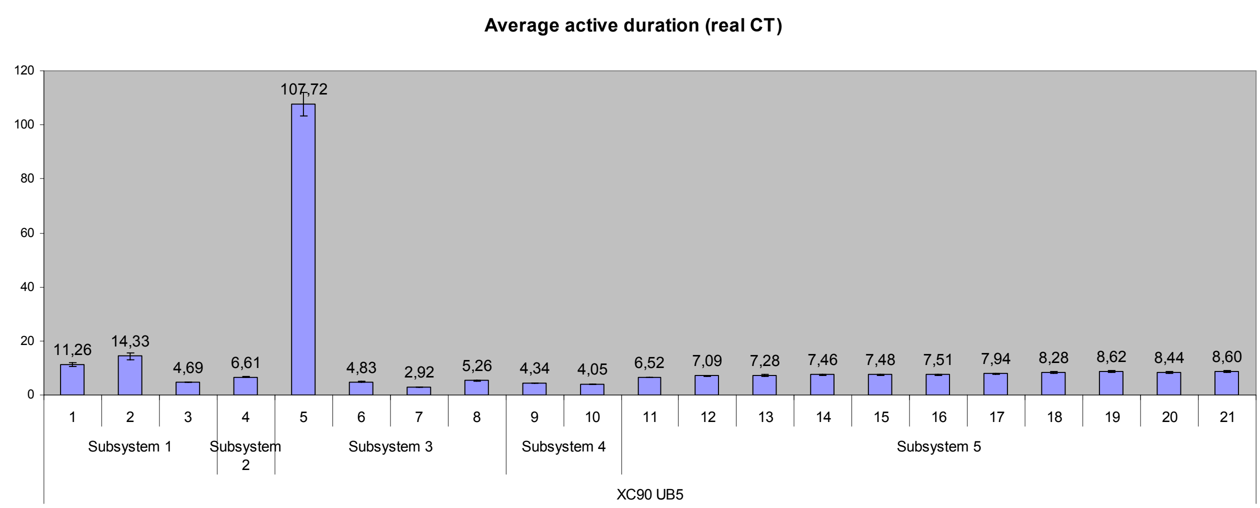

Figure 5: Average Active Period of Each Safety Area

Figure 7 presents a Pareto chart for the DoE analysis. This chart shows the statistical significance of each individual factor and two factor interaction. It can be seen that factors A (CT1), D (CT2) and F (CT3) have a significant impact on the JPH of the system. The two-way interactions AD and AE also have good statistical significance.

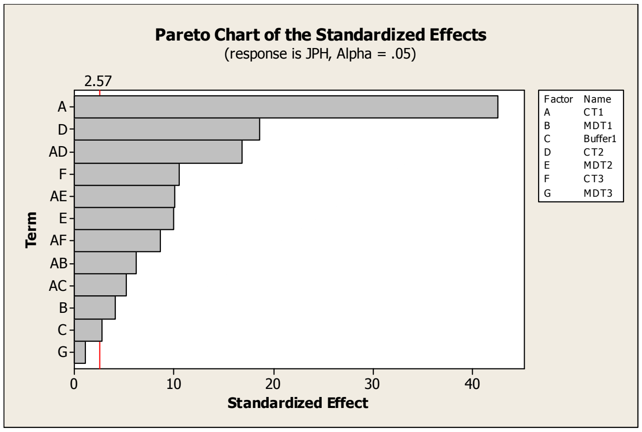

Figure 7: Pareto Chart of the Standardized Effects

7 ANALYSIS OF RESULTS

The bottleneck detection method pointed out the safety areas that constrain the manufacturing system the most in the following ascending order :

1. Safety area 5
2. Safety area 2
3. Safety area 1

As shown in Figure 8, the input factors that most affect the JPH are in ascending order:

1. Cycle time (CT1) of Safety area 5
2. Cycle time (CT2) of safety area 2
3. Cycle time (CT3 of safety area 1

By reducing CT1 from its highest level to its lowest level, 1.6 more cars can be produced per hour. If the same approach is applied to CT2 and CT3, the JPH will increase by an additional 0.7 and 0.4 cars per hour, respectively.

This indicates that the bottleneck detection method identifies correctly the primary and secondary bottlenecks in the manufacturing system. It is most likely that reducing the cycle time (CT1) of the primary bottleneck (safety area 5) will increase the gains in terms of JPH. The same logic can be observed for the secondary (CT2 of safety area 2) and tertiary (CT3 of safety area 1) bottlenecks.

Alternatively, it can be seen that the construction of a buffer with maximum capacity of 4 units immediately after the primary bottleneck will improve the JPH by only 0.1 cars per hour.

Data in Figure 7 also shows that decreasing the mean down time (MDT2) of safety area 2 at the same time as slightly reducing the cycle time (CT1) of the primary bottleneck (safety area 5), which corresponds to the two-way interaction AE, is an effective improvement alternative. Since it is rather easier to reduce mean down times than cycle times of safety areas, this improvement alternative has to be further discussed.

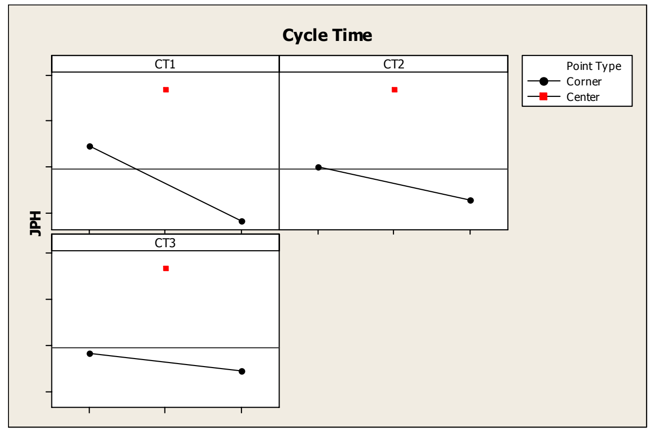

Figure 8: Contrast Plots of Cycle Times

8 CONCLUSION

The outcomes of this study show that new work methods concerning flow simulation can be effectively integrated in the application phase of a simulation project. The benefits achieved include better accuracy when carrying out bottleneck analysis, higher approximation to the customers of simulation studies due to integration of simulation outputs with their working tools, such as MS Excel, and fastest delivery of suggestions for improvements.

As a result DES can be successfully applied to support running production systems in their improvement efforts for lean manufacturing.

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APPENDIX: UB5 SYSTEM STRUCTURE

Figure A-1 shows the conceptual model of the under body process of the XC90 production flow (UB5) at VCT.

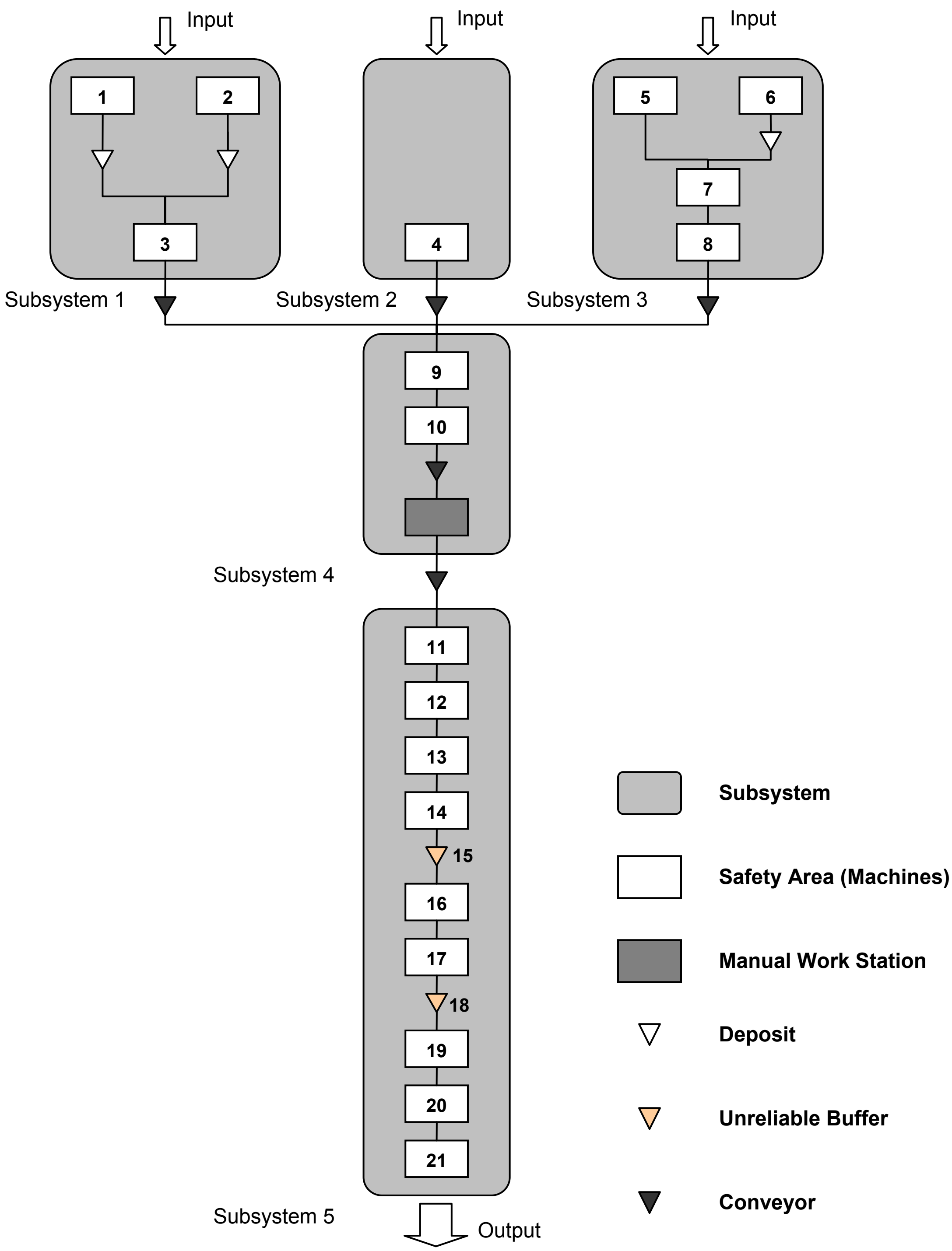

Figure A-1: Conceptual Model of the XC90 Under Body Process

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