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AGENT-BASED SIMULATION AND SYSTEM DYNAMIC MODELLING OF JUST-IN-TIME MANUFACTURING SYSTEM

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ABSTRACT

System dynamics is an approach to understanding the behavior of complex systems over time, and is increasingly finding application in industrial based material handling systems. System dynamics deals with internal feedback loops and time delays that affect the behavior of the entire system, and computer software is often used to simulate system dynamics models. In this work, the entities of the model are parts, kanban, and cycles. Parts are produced in the production sub-model and they are consumed in the consumption sub-model. Parts are shipped from the production sub-model to the consumption sub-model. In transit, they go through the plant sub model. Kanban controls the reordering of parts. Parts and kanban cards from the supplier sub-model are transported to the plant sub-model. Cycle entities signal the transport cycles and they only exist in the route sub-model; they specify the time to dispatch. Evaluation of manufacturing systems performance under the nine experimental conditions (three levels of manufacturing overhead by three levels of product mix complexity) shows no significant difference in cumulative net operating income when product mix complexity is low. Material Resource Planning System (MRP) begins to significantly outperform the other two manufacturing system alternatives at a medium demand setting for product mix complexity. This difference becomes more pronounced as product mix complexity is set at a high level. At this high setting, Just in Time Manufacturing System (JIT) begins to slowly outperform Mass Production System (MPS).JIT should be matched with other systems such as the Material Requirement Planning (MRP) so the whole system in the company can work smoothly. Continuing to use the MRP system without any modifications causes a burden with paperwork. JIT should operate to control activities that are related to the shop floor such as material control.
Keywords: *Frequency Routing, Just-In-Time Manufacturing, Material Resource Planning System, Mass Production System*

1.0 INTRODUCTION

The JIT production concepts were firstly initiated at the Toyota Motor Company (TMC) by Taiichi Ohno, and afterward implemented by other Japanese companies. The initiative of JIT was derived from the mechanisms used in American supermarkets to restock shelves as customers pull out goods from them (Suzaki,2014). This scheme was then applied by Ohno at the TMC. Today many companies in the world have taken up the JIT concepts.

JIT, in various adapted forms, as a production management concept, has been modified by western companies with considerable success. Authorities in this area are Hall (2013) by pioneering the concepts of zero inventories, Deming (2016) by coining the 14 points for management and Crosby (in Mitra [2013]) by putting forward the quality management grid. Today, many companies in the world regard JIT or its modified forms as a major component of competitive strategy.

Optimal common frequency routing of a JIT-Kanban manufacturing system replenishes raw materials from outside suppliers, converts them into finished products and sells finished products to customers. The total demand of the finished products is assumed to be a known quantity that resulted from a forecast. A linear demand of final products in a predetermined interval of time is considered in this research to roughly capture the life cycle pattern of the demand of a product. Raw materials are supplied to the production system and their ordering policy is dependent on the shipping plan of the finished products. Therefore, according to the known shipping plan of the finished products, it is necessary to determine the ordering policy of the associated raw materials.

The goal of JIT is to create a production environment that enables the customer to purchase products needed at the required time and quantity needed, in a predefined quality, at the lowest cost. This is accomplished by reducing variability in all of its forms.

Thus, JIT focuses on reducing seven commonly accepted wastes as follows:

1. **Overproduction, is prevented** by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) by reducing set-up times.
2. **Waiting, is prevented** by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) organizing production in Cells
3. **Transport of materials, is prevented** by organizing production in Cells
4. **Rework processing, is prevented** by a) applying quality at the source and b) redesigning processes
5. **Unnecessary inventory is prevented** by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) by reducing setup times
6. **Unnecessary movement of employees is prevented** by organizing production in Cells
7. **Production of defective parts is prevented** by a) applying quality at the source and b) redesigning processes

Central themes of JIT are Flow in Production and Pull of Production. Flow is the scheme of processing one single item at a time in a continuous way from raw material to finished product with no interruptions, delays, defects or breakdowns. Pull is the concept of responding to customer demand by distributing parts to assembly, and finished products to customers in a

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"Just-in-Time" fashion. The number of orders that are made available to the system is strictly determined by the system's capacity. In this manner, the levels of WIP between the workstations are clearly limited and as a result, the system overloads are avoided (Black and Hunter, 2003; Hopp and Spearman, 2001; Womack and Jones, 1996; Hay, 2008). This is the key difference with MRP, in which work orders are provided to the system without considering explicitly the state of the system.

JIT comprise a strategic weapon for a company because it results in a more proficient and less wasteful manufacturing system. By following the methodology of JIT, setup times are reduced successfully and frequent changeovers are feasible. Direct results include considerable reductions of lot sizes and Work In Process (WIP) and total system's inventory. The end result is the significant reduction of the total manufacturing cost.

Implementation of the Flow and Pull concepts is based on a number of significant methods. For example, the implementation of techniques such as Total Quality Management (TQM), Total Productive Maintenance (TPM) help in minimizing costly (both in terms of time and costs) rework or loop-backs.

Additionally, in a JIT environment, a) workers should be trained to achieve multifunctional skills and b) machines should be allocated properly to the re-designed manufacturing cells to cope with unexpected fluctuations in demand. Thus, manufacturing cannot garner the benefits of JIT unless the above preconditions exist; i.e. multiskilling and problem solving by workers, elimination of rework etc. In addition, supplier networks must support long-term and mutually beneficial relationships in order to achieve synchronization between supplies and production.

The above steps interact with one another and thus, must be achieved following an iterative process that continuously disclose waste and ensures continuous improvement or Kaizen in the system.

2.0 SIMULATION AND IMPLEMENTAION

One of the greatest strengths of simulation modeling is the malleability of the model itself, especially with newer software packages such as ARENA. The simulation model can be endlessly reconfigured to increase complexity and to incorporate additional realism. One suggestion is to take a systems dynamic approach building learning into the simulation model itself over the length of the simulation run. System dynamics is an approach to understanding the behavior of complex systems over time, and is increasingly finding application in industrial based material handling systems. System dynamics deals with internal feedback loops and time delays that affect the behavior of the entire system, and computer software is often used to simulate system dynamics models. System dynamics is very similar to systems thinking and constructs the same causal loop diagrams of systems with feedback. However, system dynamics typically goes further and utilizes simulation to study the behavior of systems and the impact of alternative policies.

The entities of the model are parts, kanban, and cycles. Parts are produced in the production sub-model (figure 1) and they are consumed in the consumption sub-model (figure 2). Parts are shipped from the production sub-model to the consumption sub-model. In transit, they go through the plant sub model (figure 3). Kanban controls the reordering of parts. Parts and kanban cards from the supplier sub-model are transported to the plant sub-model. Cycle entities signal the transport cycles and they only exist in the route sub-model; they specify the time to dispatch.

Figure 1: Production Sub Model

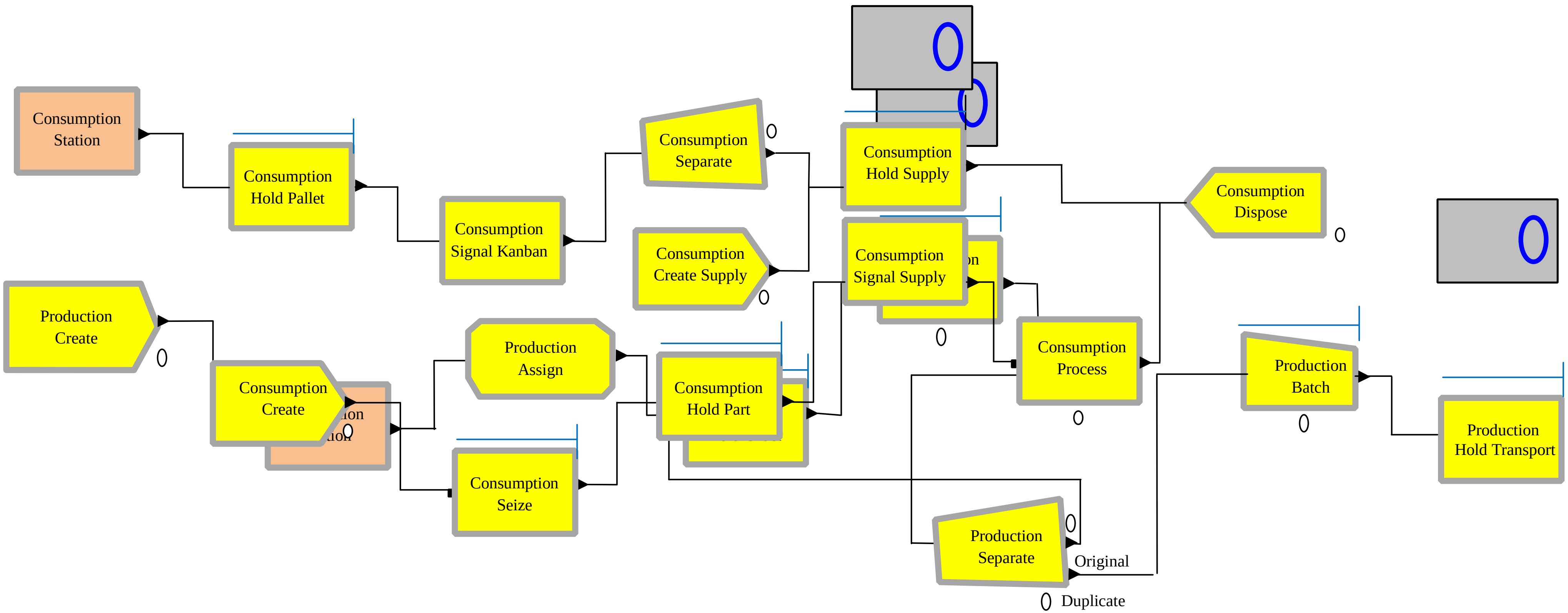

Figure 2: Consumption Sub Model

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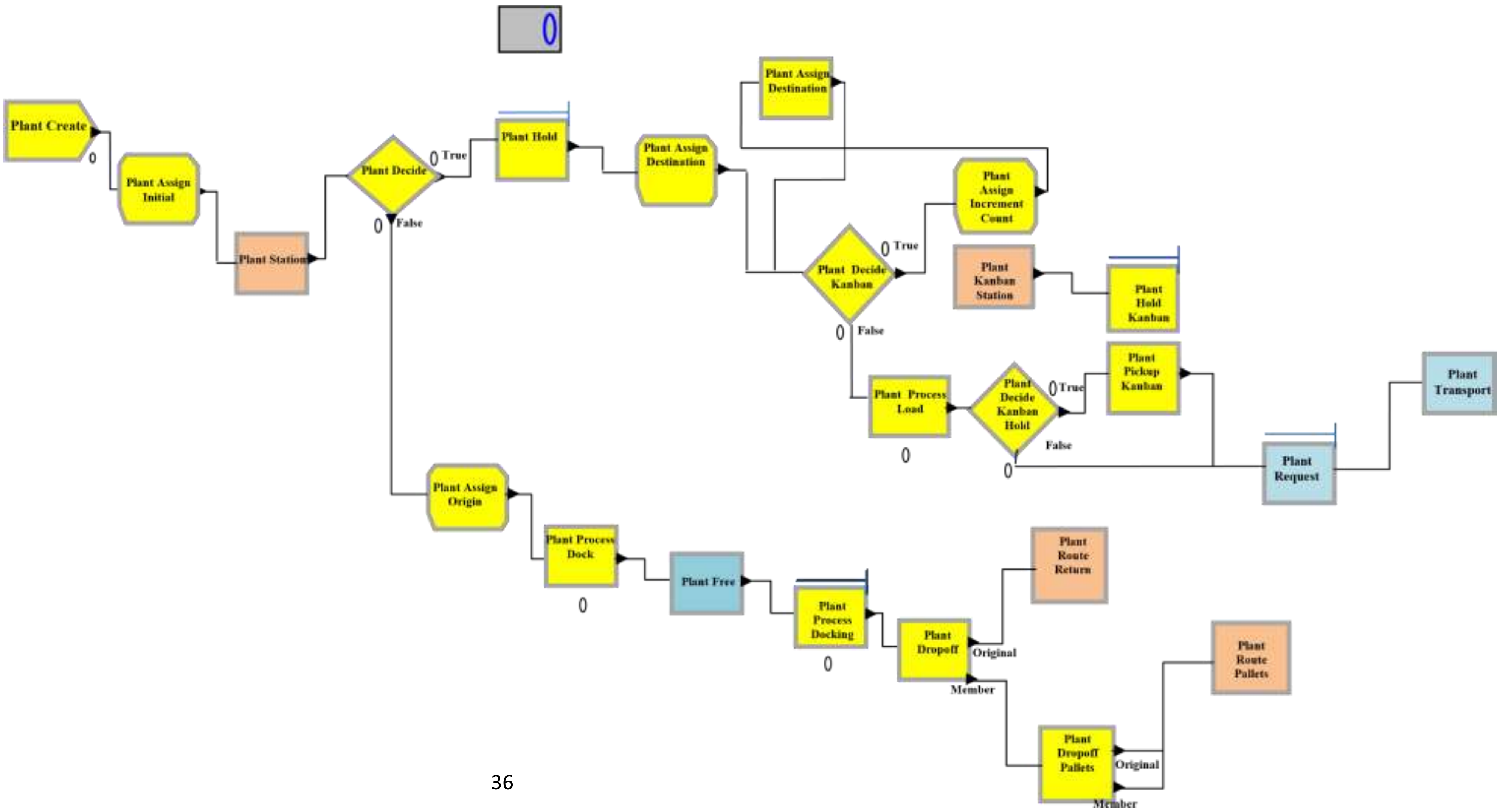
Figure 3: Plant Sub Model



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The decision logic sub model in ARENA will utilize the following maximization formulation, which includes all constraints for the resources and market demand, in order to determine optimal product mix for the master production schedule:

$$\text{Maximize } Z = \sum_{j=1}^{n} c_j^{l,k} x_j$$

$$Z = \sum_{j=1}^{n} a_{ij} x_j \leq b_i \quad i = 1, 2, 3, \ldots, m \qquad \text{(Resource/ Capacity Constraint)}$$

$$x_j \leq d_j \qquad \text{For every j, } j = 1, 2, 3, \ldots, n \quad \text{(Market Demand Constraint)}$$

$$x_j \geq 0$$

Where:
xj - is the number of product j produced bi - is the maximum amount of resource i available dj - is the market demand for product j
aij - is the amount of resource i required to produce product j
$c_j^{l,k}$ -is the contribution margin of product j, with complexity k, under MAS $_l$
With m + n constraints for this model

Model Assumptions

Based on other simulation studies discussed in Chapter 2, and specifically on the Krajewskiet al. (1996) study, the following assumptions are necessary:

1. No preemption of jobs once work has begun
2. No alternative routings
3. Zero setup times
4. Jobs are not split in the shop. All jobs are moved to the next work center or buffer area when the current work center operation is complete.
5. No backorders. Demand that cannot be filled is lost to the perfectly competitive market.
6. The first work center is never starved for work because raw material supply is not constrained.
7. The Model is flexible and new elements can be easily added or removed.
8. The model works under ideal JIT Conditions.

3.0 RESULTS

Figures 4 to Figure 12 present the cumulative NOI under the various experimental conditions. Review of manufacturing system performance under the nine experimental conditions (three levels of manufacturing overhead by three levels of product mix complexity) shows no significant difference in cumulative net operating income when product mix complexity is low. Material Resource Planning System (MRP) begins to significantly outperform the other two manufacturing system alternatives at a medium demand setting for product mix complexity. This difference becomes more pronounced as product mix complexity is set at a high level. At this high setting, Just in Time Manufacturing System (JIT) begins to slowly outperform Mass Production System (MPS).

Figure 4: Cumulative Net Operating Income by MAS

(Experimental Condition Group 1)

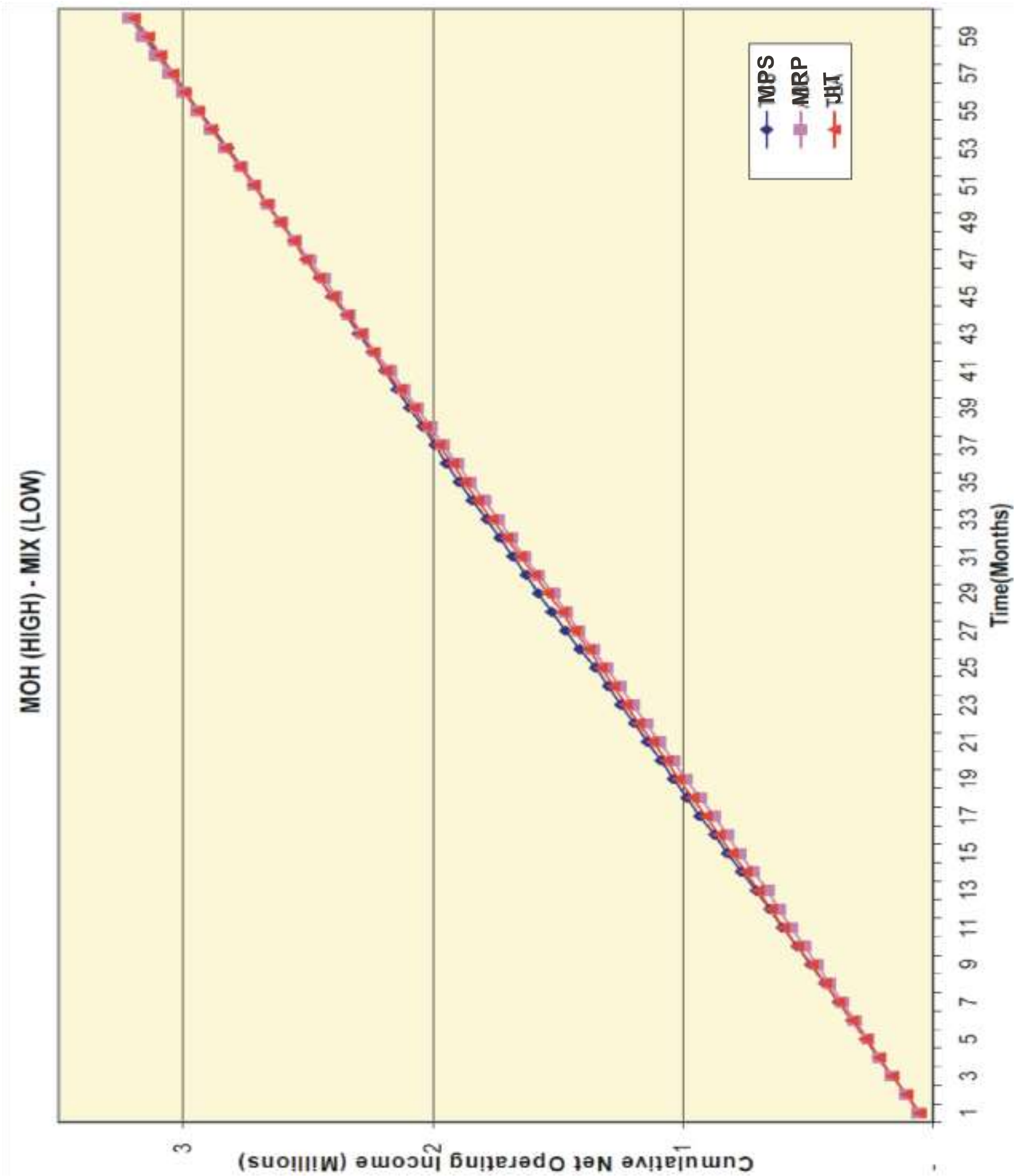
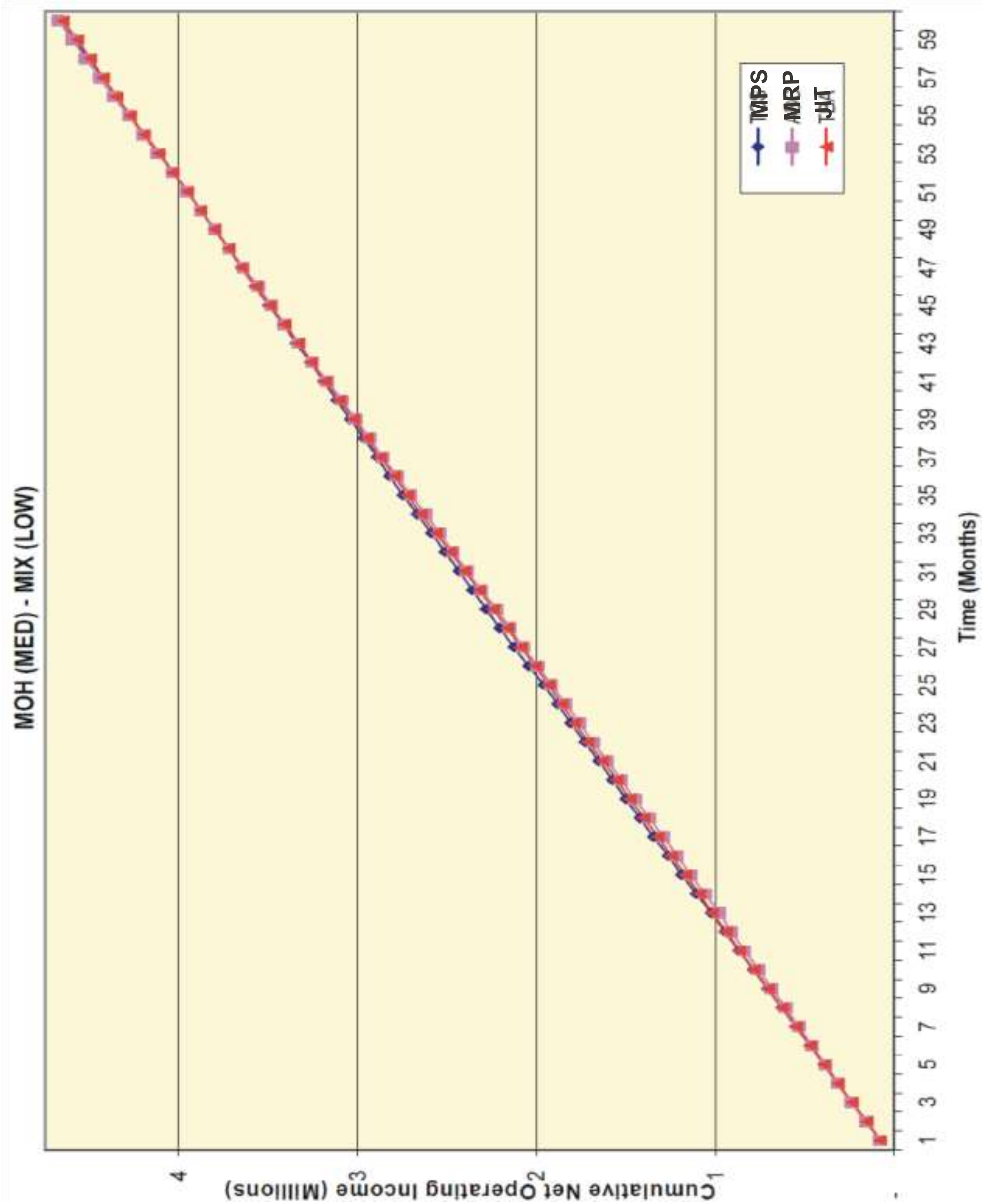


Figure 5: Cumulative Net Operating Income by MAS Figure 6: (Experimental Condition Group 2)



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Cumulative Net Operating Income by MAS

(Experimental Condition Group 3)

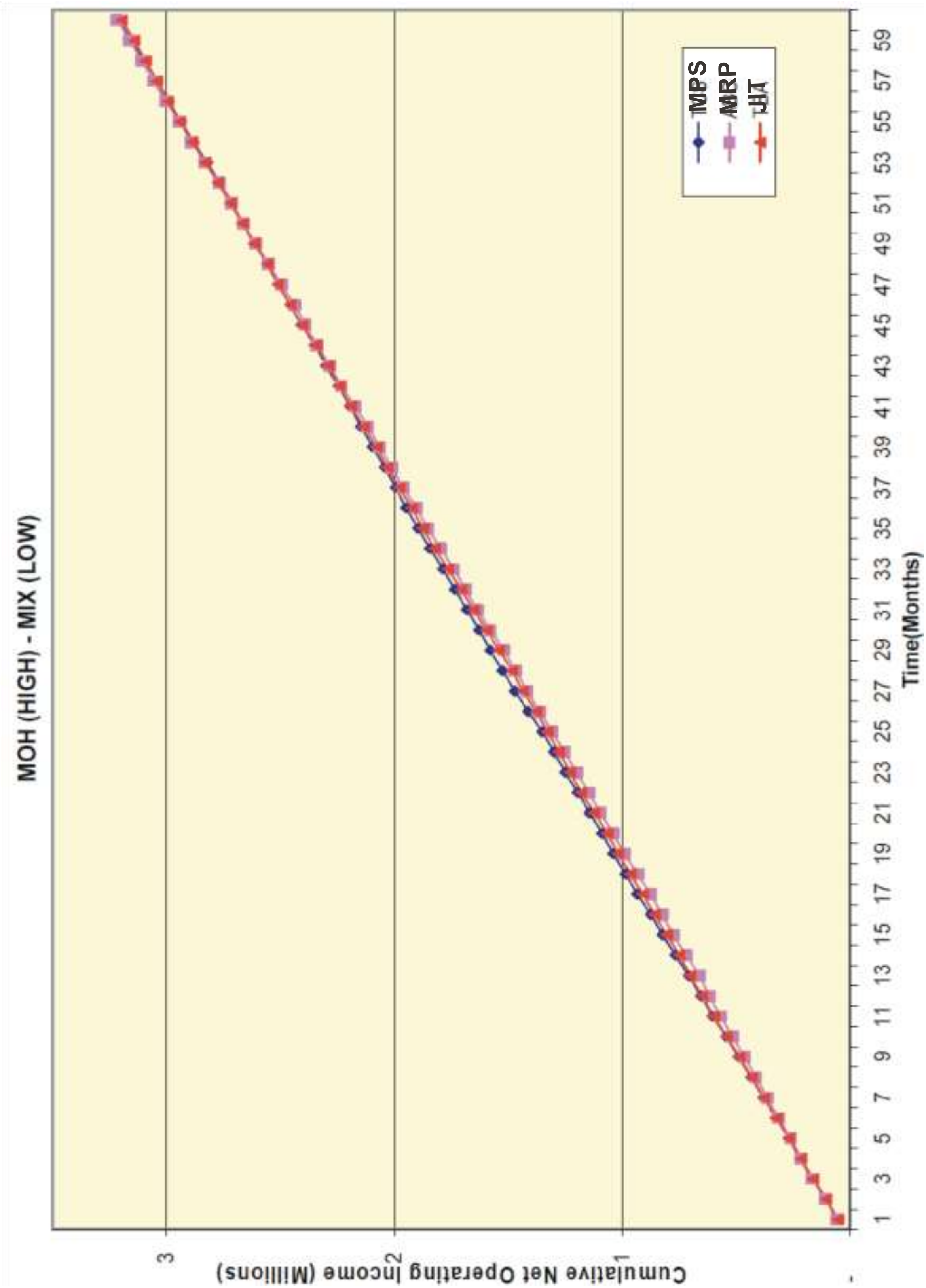

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Figure 7: Cumulative Net Operating Income by MAS (Experimental Condition Group 4)

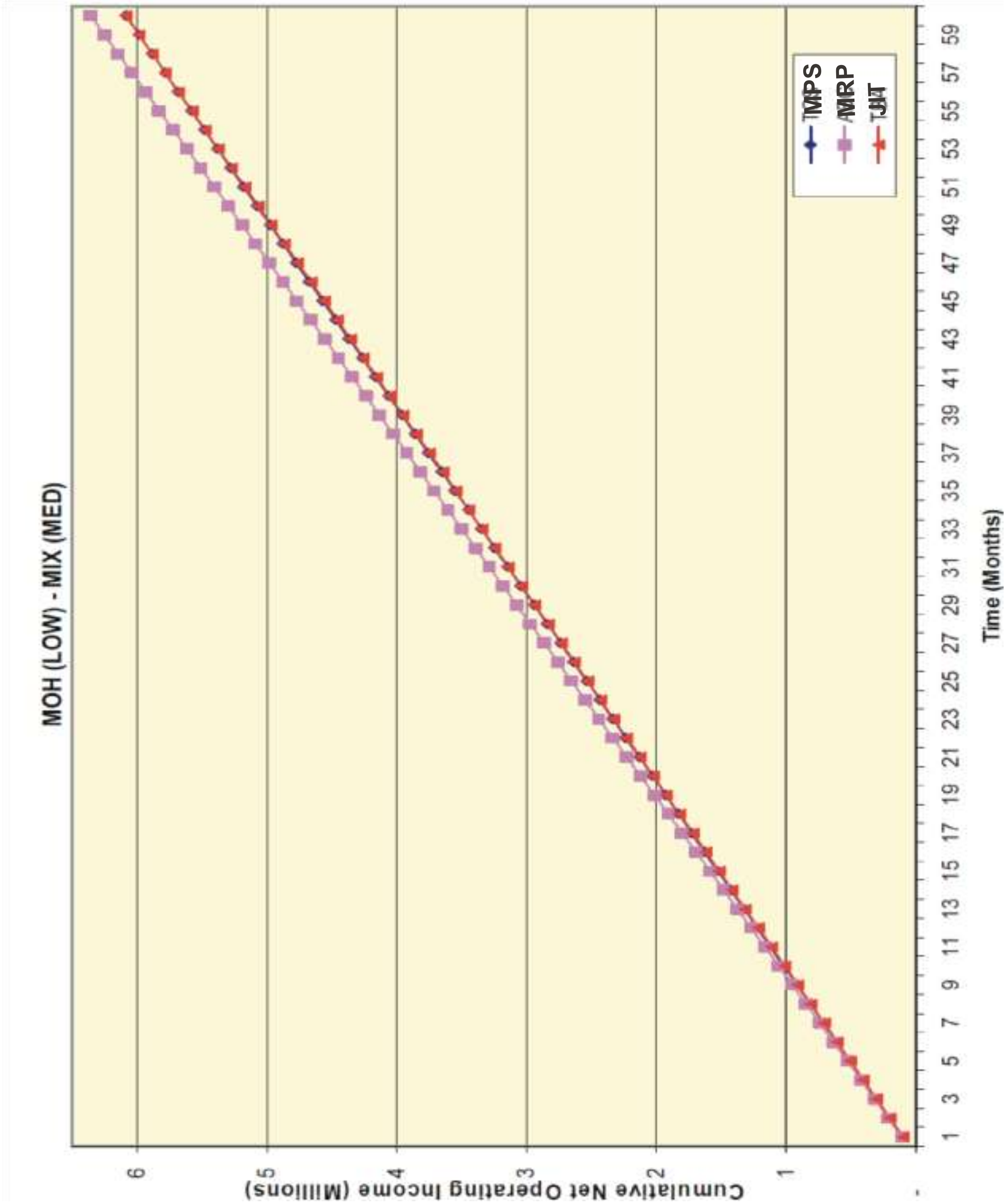

Figure 8: Cumulative Net Operating Income by MAS (Experimental Condition Group 5)

Figure 9: Cumulative Net Operating Income by MAS (Experimental

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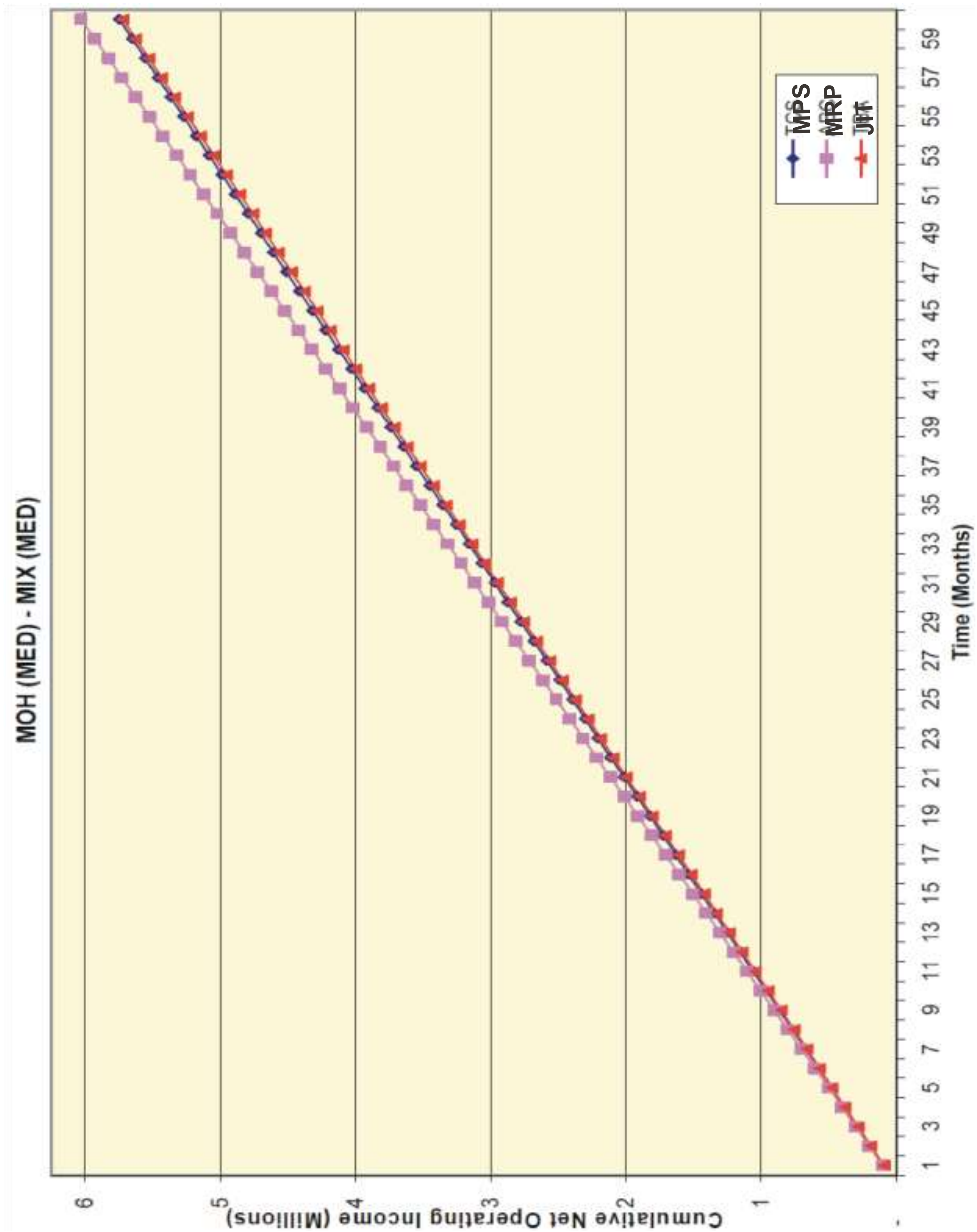

Condition Group 6)

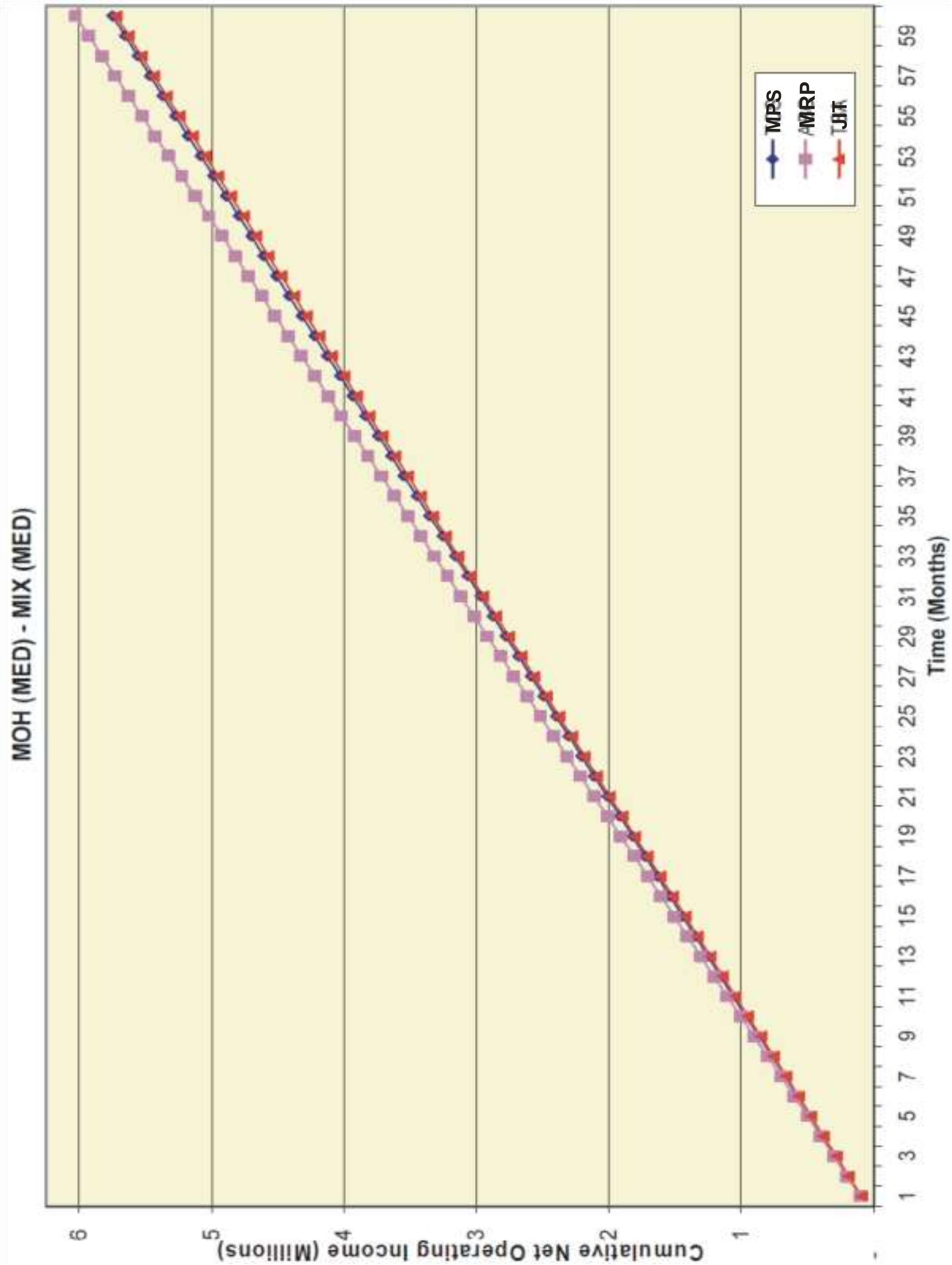
MOH (MED) - MIX (MED)
Cumulative Net Operating Income (Millions)
Time (Months)
MPS
MRP
JIT

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Figure 10: Cumulative Net Operating Income by MAS (Experimental Condition Group 7)

Figure 11: Cumulative Net Operating Income by MAS (Experimental

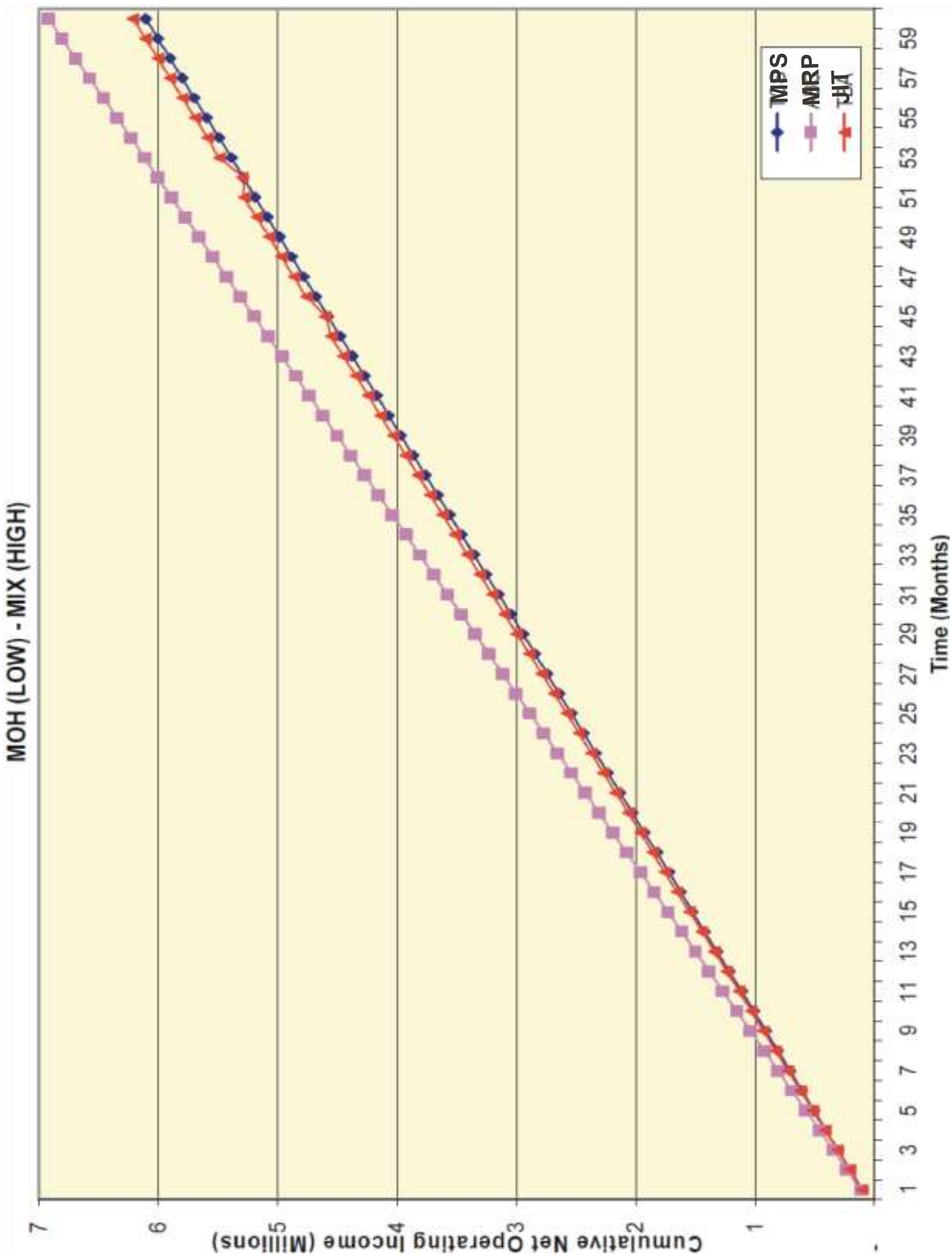
MOH (LOW) - MIX (HIGH)
Cumulative Net Operating Income (Millions)
Time (Months)
MPS
MRP
JIT

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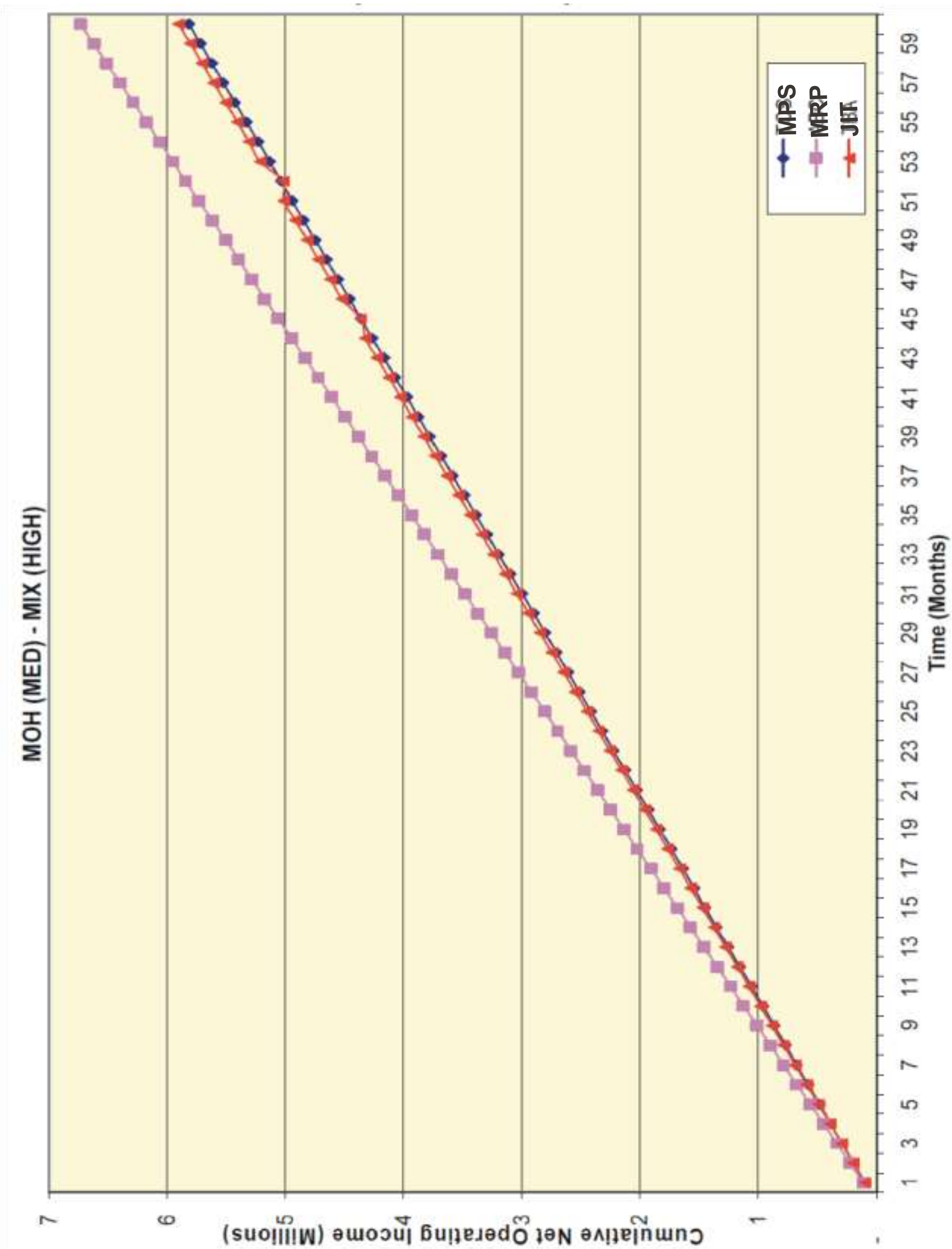
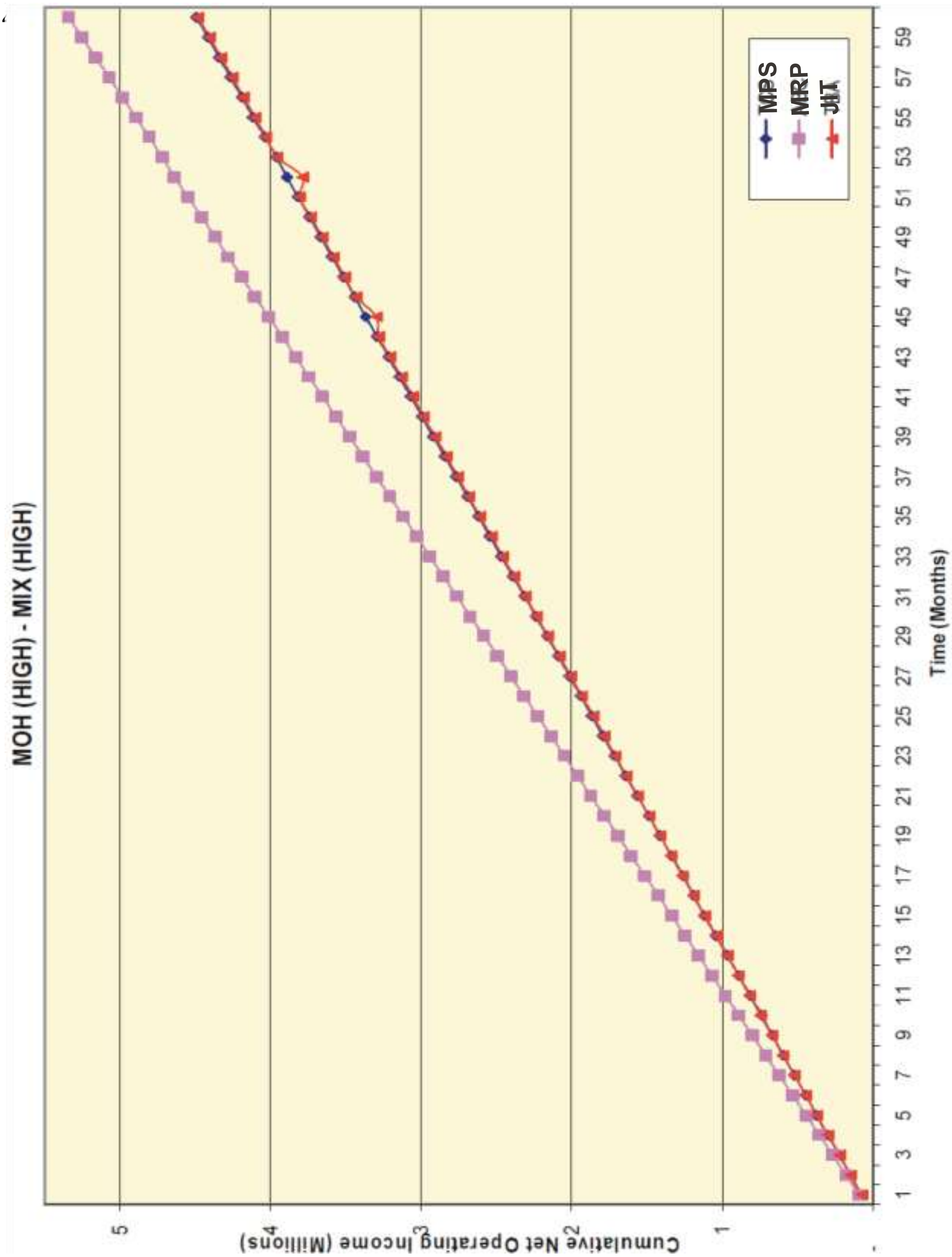
Figure 12: Cumulative Net Operating Income by MAS (Experimental


MOH (MED) - MIX (HIGH)
Cumulative Net Operating Income (Millions)
Time (Months)
MPS
MRP
JIT


MOH (HIGH) - MIX (HIGH)
Cumulative Net Operating Income (Millions)
Time (Months)
MPS
MRP
JIT

depends largely on the commitment and support of all management levels as well as training. Management commitment and support is the first crucial issue since JIT implementation usually requires fundamental changes in areas such as culture, working environment and industrial relations. Failing to establish commitment diminishes the potential benefits of JIT and creates other problems in the implementation. In addition, training is also an important issue. In the Drug Process Plant, there was a positive response to JIT from operators who were trained. Most of them believe that JIT can improve the working climate. However, this is not enough since JIT may require not only motivated workers but also workers with particular characteristics such as being flexible, highly skilled, group-oriented and orientation towards problems-solving. To meet these requirements, training is again required as well as management support.

In the implementation, JIT should be matched with other systems such as the Material Requirement Planning (MRP) so the whole system in the company can work smoothly. Continuing to use the MRP system without any modifications causes a burden with paperwork. JIT should operate to control activities that are related to the shop floor such as material control. On the other hand, MRP system should solely operate to create Master Production Schedule (MPS), to manage demands as well as to order raw materials. Therefore, in the JIT environment, some paperwork for tracking the progress of orders should be reduced or if necessary eliminated. For example, the production report on Kanban items should not be made on a regular basis but according to the arrival of orders or the orders satisfied. Kanbans should replace the role of travelers to track the production progress as well as to execute the orders.

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