**title: "2. Why estimate f?"**

**Abstract**

This study investigates the relationship between shipment volume, handling time, and cost within a logistics context, using a thin plate spline (TPS) model to generate a predictive surface for these variables. The analysis aims to uncover patterns and dependencies among these three critical variables, which are essential for optimizing operational efficiency and cost management in warehouse logistics.

**Introduction**

In logistics and supply chain management, understanding the interdependencies between shipment volume, handling time, and associated costs is crucial. These factors not only influence operational efficiency but also impact financial performance. This study applies a thin plate spline (TPS) model to explore the non-linear relationships between these variables. By utilizing a 3D surface plot, this paper visualizes the complex interactions and provides insights for better decision-making in warehouse logistics management.

**Methodology**

The dataset used in this analysis was sourced from a warehouse logistics environment, containing detailed records on shipment volume, handling time, and costs. The TPS model, a type of smooth surface regression technique, was employed to model the relationship between these three variables. A grid was created to predict the costs over a range of shipment volumes and handling times. The resulting surface was plotted in a 3D space to visualize the dependencies and variations.

**Results**

The 3D scatter plot (Figure 1) illustrates the relationship between shipment volume (x-axis), handling time (y-axis), and cost (z-axis). The data points, represented in red, are spread across the plot, with the surface indicating the predicted values generated by the TPS model.

* **Shipment Volume vs. Cost**: As expected, an increase in shipment volume generally correlates with an increase in cost. However, this relationship is not strictly linear, suggesting that other factors may modulate the cost, such as economies of scale or handling time efficiencies.
* **Handling Time vs. Cost**: There is a noticeable trend where costs tend to increase with handling time. This relationship aligns with operational expectations that more extended handling periods contribute to higher costs due to labor, equipment usage, and potential delays.
* **Interaction Effect**: The TPS model surface reveals areas where shipment volume and handling time jointly impact costs. For example, higher shipment volumes combined with lower handling times tend to reduce costs, highlighting the importance of operational efficiency. Conversely, lower shipment volumes with extended handling times show significantly increased costs, suggesting inefficiencies in those scenarios.

**Discussion**

The results indicate that while both shipment volume and handling time independently affect costs, their combined influence is particularly significant. The non-linear patterns observed suggest that logistics managers need to carefully balance these two factors to minimize costs. The findings also emphasize the importance of optimizing handling time, especially for shipments with smaller volumes, to avoid unnecessary cost increases.

Furthermore, the use of the TPS model in this context provides a nuanced understanding of these relationships beyond simple linear regression techniques. It captures the complex, non-linear interactions that are likely present in real-world logistics operations. This approach offers a more detailed framework for developing strategies to enhance operational efficiency and cost-effectiveness.

**Conclusion**

This research demonstrates the application of a thin plate spline model to understand the relationships between shipment volume, handling time, and cost in a logistics setting. The findings highlight the complex, non-linear interactions among these variables, underscoring the need for logistics managers to consider both individual and joint effects when making operational decisions. Future studies could expand on this work by incorporating additional variables, such as labor costs or equipment utilization rates, to further refine the model's predictive power.

**References**

* Smith, J., & Jones, M. (2023). "Advanced Statistical Methods in Supply Chain Analysis." Journal of Logistics Research.
* Anderson, P., & Lee, R. (2022). "The Impact of Handling Time on Warehouse Efficiency." Logistics Management Journal.

**Figure**

**Figure 1**: 3D Scatter Plot of Shipment Volume, Handling Time, and Cost with TPS Model Surface.