Abstract: In the global market, which is diversifying year by year, the competitions in 2 pedal transmission technologies, especially among AT, CVT and DCT have been getting severe. Comparing pros-and-cons in AT, CVT and DCT as current customer perceptions in the markets, still each technology have room to evolve to meet customer satisfactions. This paper focuses on CVT future technological potentials to improve customer satisfactions further in the global markets mainly in terms of drivability and fuel economy.

1. Global Transmission Volume ('05)

This chart (Figure 1) shows global transmission production volume. As of 2005, the total volume is 60,850K units.

European market has the largest volume in the world, where MT accounts for majority.

On the other hand, North America and Japan are second and third largest markets where AT accounts for majority.

When we look to the emerging markets, BRICs, it is growing to reach the same size as Japanese market. In these markets, MT ratio is higher than AT at the moment.

AT & CVT Volume Trend – Europe:
With the following slides of transmission annual volume, let's look and see the trends in the major markets.

In Europe (Figure 2), the environmental regulations like CO2 V.A (voluntary agreement) and EURO4/5 are getting severe. The diesel engine penetration is particularly higher than the other markets. In this market, the majority of transmissions is manual. As for 2 pedal transmissions, FWD and RWD are likely to move to multiple steps.

Turning to FWD vehicles, the various technologies have been rising for 2 pedal transmissions, AMT, DCT, Step AT and CVT. As you see in the FWD vehicles, AMT/DCT share would increase, as the market grows. 6AT would increase replacing 5AT. Attentions are focused on which transmission technology will be the most practical and acceptable in this market.
In this market also, the environmental factors like CAFÉ and Emission regulations are the keys to move the transmission trend. Multi-step AT and CVT have been introduced increasingly (Figure 3).

For FWD vehicles, 6AT would become dominant around 2010, while 4AT decreases significantly. CVT would have slight but gradual increase trend. DCT seems to be a slight increase after the market introduction in 2003.

For RWD vehicles, 6 or more step AT is expected to increase.

The introduction of New Fuel Economy Standard in 2010 and incentive of Green Tax have been the driver of the transmission trend both in FWD and RWD vehicles.

This chart (Figure 4) describes that the increasing demand for improved fuel economy has generated the shift to CVT particularly in B and C segments under 250Nm for FWD vehicles. CVT would continue to grow, replacing 4AT in these segments.

For RWD vehicles, the trend shows the direction to multiple steps AT with 6 speeds and more. In this year 2006, 8AT was introduced into the Japanese market. 8AT is also introduced in Europe as well as North America.

Total volume will be growing rapidly for FWD in particular. MT is dominant in this market. When it comes to 2 pedal transmissions, 4AT is the majority for FWD at present. There would be an opportunity for cost competitive 4AT to grow. Furthermore, in China, for instance, customers are interested in the new technologies such as CVT and multiple steps AT. Then 5AT, 6AT, and CVT are expected to increase (Figure 5).

For RWD vehicles, MT would occupy the majority.

Summarizing the market trend (Figure 6), we can see the trend is driven by the influences of environment-related requirements of fuel economy and emission regulations.

**Summary of Market Trends**

- **EURO**: AMT and DCT would increase, though MT is major; various 2 pedal TM technologies incl. 6AT and CVT would exist.
- **US**: Multiple step AT become major; CVT will increase; DCT debuted.
- **JPN**: CVT become major in B & C segment; Multiple step AT increases in D segment and above; CVT and step AT would co-exist.
- **BRICs**: MT is major; Opportunities for volume increase of 2 pedal technologies, ex. Multiple step AT and CVT in China.
Looking to 2 pedal technologies, the transmissions direct to multiple steps and step-less. Various types of technologies have been developing through competitions each other, as the markets are diversified.

To be the best transmission will depend on how far it can meet market needs and customer satisfactions.

Sales of Mini-Car in Japan (by TMs): This graph (Figure 7) shows Mini-car past sales and its sales forecast in Japan by transmissions. As shown, the car sales with CVT are expected to grow replacing AT since this year. We believe this is because the needs for the better fuel economy and driving performance are also increasing in the mini-car segment.

2. Market perceptions in automatic transmissions

Conventional Market Perceptions and Issues: Talking about new technology of 2 pedal transmissions, it is practical to consider what the conventional transmission was for each market. In Europe, for example, customers switch MT to 6AT/CVT/DCT. In US and Japan, customers switch 4AT to 6AT/CVT/DCT.

Under these circumstances, every technology continues to develop dramatically in terms of driving performance and fuel economy. However, each technology still has some issues and weakness to overcome to meet the market and customer satisfactions.

This slide (Figure 8) tries to pick up the issues related to CVT, 6AT and DCT by the markets.

In Europe, CVT has received the feedback specified as rubber band feeling and weakness at Highway fuel economy.

In US, CVT have had the same evaluations like in Europe. DCT would have weakness in launching performance due to torque-converter-less mechanism and in booming noise, which is likely to occur when a car is re-accelerated at a lower speed.

In Japan, DCT would have the same evaluations like in US.

6AT has some difficulties in city fuel economy and controlling shift in each market.

The following slides will explain the current and future potentials to enhance the balanced improvement both for driving performance and fuel economy, focusing on CVT technology.

3. Technological potentials to meet the future trends

Raito Coverage: Now let’s see briefly the history of ratio coverage (Figure 9), it is getting wider as step AT has increased steps and CVT and DCT are marketed. Now the ratio coverage of 6 and above can be
selected. In the future, the ratio coverage might become much wider because the market and customer expect both better Fuel Economy and better driving performance. We assume CVT stores potentials to meet these without big change in packaging.

Launching Acceleration image: CVT/6AT/DCT. This slide (Figure 10) shows the comparison of launching acceleration performance among CVT, 6AT and DCT.

CVT and 6AT realize quicker launching acceleration than DCT due to torque converter as a starting device. The torque converter, furthermore, helps acceleration G reach peak quicker and maintain acceleration feeling. This launching feel is well accepted in the market like US and Japan where torque converter is very common starting device.

Linearity from Rubber band feel: Next is linearity and rubber band feel in acceleration from the speed, 40km/h (Figure 11).

With Old CVT (the black line), it takes time the acceleration G to reach peak and the G decreases after the peak point. In this situation, when you step on the gas, the engine revolution goes up too high first and then the vehicle speed picks up later. This behavior is so-called rubber band feel.

On the other hand, new generation CVT (the red line) enables the acceleration G to reach peak faster and to continue to stay. In this situation, the negative feeling of rubber band would be much improved.

Linearity Improvement: With old CVT, immediately after downshifting, the gear ratio shifts to higher ratio, or up-shifting. This leaves the acceleration G decrease after the engine revolution goes up.

However, with new generation CVT, the gear ratio is fixed at a certain ratio in order to keep the acceleration G while the engine revolution is going up (Figure 12).
In the result, the rubber band feel can be swept away.

**Fuel Economy – BSFC:** This chart (Figure 13) shows the zone where CVT and step transmission are used in BSFC.

![Figure 13](image)

CVT, using continuously variable gear ratio, is able to select and utilize the most engine-energy efficient zone, as compared with transmission using fixed gear ratio. This is one of the CVT advantages over the step transmissions.

**Fuel Economy – Fuel cut:** Another effective measure to improve fuel economy is fuel cut during coasting conditions. This offers significant benefit to fuel economy improvement.

![Figure 14](image)

The graph on the left (Figure 14) shows the relation of vehicle speed and primary pulley revolution. The graph on the right (Figure 14) shows the relation of time in seconds and engine speed.

As you see, while DCT is able to implement the fuel cut till the vehicle speed reaches 40km/h, CVT realizes longer fuel cut time till the vehicle speed reaches 20km/h. This results from maximizing the advantage of using continuous pulley ratio change to keep engine revolution higher to obtain the longer fuel cut time.

**Fuel Economy – CVT Friction loss:** Next factor to contribute to FE is friction loss of CVT (Figure 15). Currently CVT’s friction loss is greater than 6AT and DCT in city driving as well as in highway driving zones. When it comes to the main contributors to friction loss, loss from oil pump, belt & pulley accounts for over 50%. But there are potentials to improve the current friction loss to enhance efficiency.

Our target of friction loss reduction will be; about 20-40% in the city driving zone, and about 10-30% in highway driving zone. By achieving the target, the friction loss level is expected to approach that of 6AT and DCT.

![Figure 15](image)

How to reduce the friction loss is described here. From oil pump and belt & pulley, it requires oil pressure optimization for belt clumping. The measures will be to utilize variable flow oil pump, belt slip control strategy, hydraulic control valve design optimization, etc. From other items, the potentials lie in utilizing high friction clutch facing and developing CVT effective structure/architecture.
The FE improvement potentials can be explained with the combination of afore-mentioned CVT technologies (Figure 16). We believe the future CVT has potentials to realize much better FE than the other transmission technologies by means of enhancing CVT advantages, like longer fuel shut off time and better usage of BSFC zone, and by means of overcoming disadvantages like friction loss.

4. Aspects in future automatic transmissions

Future automatic transmission: As an aspect of future transmissions, we believe the most important thing is to meet market and customer satisfactions. It is the value for us to transmit satisfactions to the market and the customers. In order to achieve that objective, the market diversity and customer needs are our driver to develop the technological potentials.

At present, step AT, DCT and CVT transmission technologies have evolved remarkably to achieve the same objective. JATCO, as an expertise in CVT technology, still finds further technological potentials in CVT and challenges to bring our CVT to the best technology to meet higher market and customer satisfactions in the future (Figure 17).